

**ON THE ROLE THAT SPECIFIC DOMAIN KNOWLEDGE AND  
PROCEDURAL STRATEGIES PLAY IN DEFINING THE EPISODIC  
NATURE OF ARCHITECTURAL DESIGN FORMULATION**

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To Lucas, and Magdalena. Fly high!!

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## SUMMARY

This dissertation presents a study of design activity based on the analyses of fifty-six design processes taken from fourteen designers which were give four related architectural problems. The motivating interest was to investigate what is specifically distinctive about the architectural design process, with a focus on how the activity is organized or planned, and on how knowledge of different kind and external visual representations—sketches—are brought into play. These considerations and interests are derived from the assumption that the cognitive processes underlying the design activity are embodied and distributed throughout the materials and techniques used for the purpose.

Findings reveal that the design activity is structured episodically, a feature that is not yet discussed adequately within extant literature on the topic. Episodes are described as forms of continuous activity grounded in specific forms of external representations and addressing a cluster of related sub-problems. Results also showed that unfamiliar tasks and settings generated larger number of episodes, which is conformity with the thesis that architects address novel design challenges by breaking up the overall design task into a number of smaller and more familiar sub-tasks, but that this restructuring emerges during the context of the design.

Further findings concern the nature of these episodes. Episodes were found to fall into three main types, those concerned with issues of program and spatial organization, those concerned with site and physical context, and those with formulating broad goals. The quality of the designs depended not so much on the number of such episodes, or their

order, but on their richness measured in terms of the number of design issues addressed within them and their variety.

## CHAPTER 1 INTRODUCTION

*“Design remains as one of the least understood of all our cognitive powers.”*

*(Lawson and Dorst 2009).*

Architects possess an odd skill that allows them to envision and define design problems regardless of how complex or big the design project is. Architects gather and analyze a considerable amount of information regarding their projects. They analyze the site in which the new building will be erected, its topography, its views, and its connections with the surrounding environment. They also envision and propose activities that will take place in the future building and formulate spaces that the future building will offer to support those activities. Architects make hundreds of design decisions before the building construction has even begun. All of these activities are common in architectural practice, and by undertaking such activities, architects drive design processes and develop design knowledge and become experts that define design problems. Architects do not create buildings. Rather, they run design processes, and such processes are cognitive processes by their very nature. However, these cognitive processes, which allows design practice to emerge are what remains less understood in the field of design cognition.

We are aware that manifestations of cognitive processes occur both inside and outside of the architect’s mind. Indeed, the interplay of such manifestations, both internal and external, is the matter of inquiry in this study. Specifically, the focus of this research is to elucidate the internal stock of knowledge that

architects develop and manage, and then to explain how this knowledge bounds the use of diagrams and sketches that architects make. Thus, the aim of this work is to delve deep into architects' cognitive processes, into their content, and into the procedures that drive the interaction of procedural and semantic representations of architectural design knowledge, and, hopefully, to expose the nature of such relationships.

### **1.1 The Formulation of Architectural Designs**

Architectural design, especially in its early phases, was recognized as different from other forms of problem solving (Archer, 1979; Eastman, 1969, 1970). In this context, such terms as “ill-defined” and “ill-structured” have been used since the late 1960's to depict the fuzzy state from which designers—architects among them—initiate their designs (Eastman 1969; Simon 1973; Cross 1982; Akin 1986; Goel 1992). Peter Rowe is among the scholars that suggested a way in which architects tackle ill-structured problems. He claims that the definition of design constraints is what allow for testing solutions against design problems or sub-problems (Rowe, 1991). Further, the notion of “design constraint,” which Rowe define as cognitive devices—heuristics in nature—recognize that architectural problems are general, open ended, and vague. This condition of vagueness carries the seed of uniqueness and the characteristic of the originality of design solutions. At the same time, such vagueness allows multiple explorations in almost any direction when architects start working on design problems. This very early phase of design is unique, and the cognitive processes

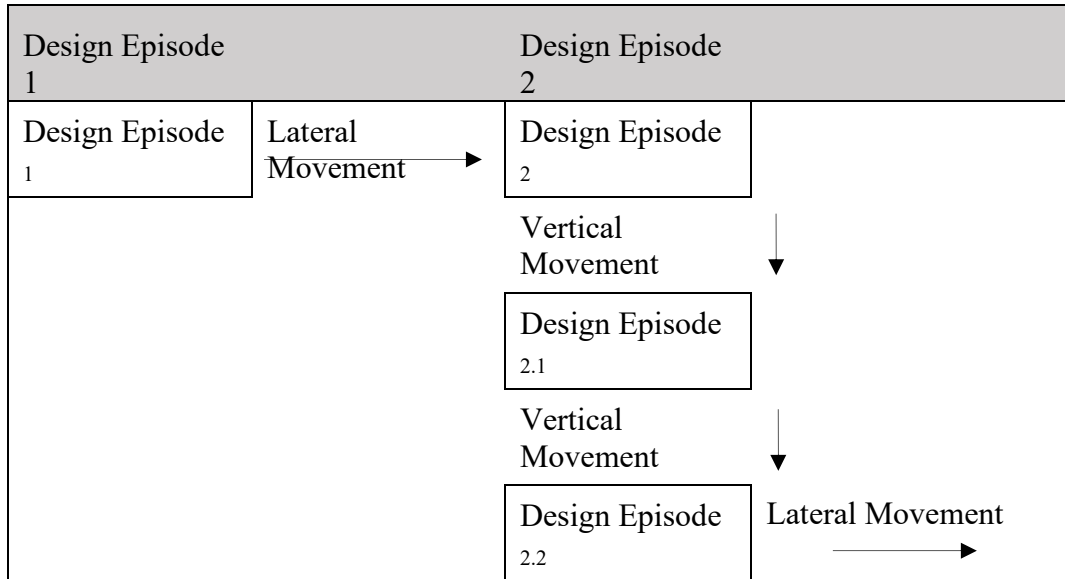
that support the elaboration of design proposals from scratch are a phenomenon this research intends to study.

In later phases, design processes reach a state in which the initial ill-defined status becomes defined, specific, and even straightforward. Hence, expressions such as “ill-defined” and “ill-structured” no longer play a role, and the design problem formulation becomes clear. This progressive change in states, which allows advancement towards the design outcome, occurs by defining design conjectures and constraints, by refining the design product through iterations, and by exploring design details. Indeed, researchers have recognized that after the initial formulation of design ideas, these ideas are tested as design solutions against different constraints.

Scholars have proposed that to perform evaluations of their design formulations, architects decompose and organize design problems into multiple levels, or sub-problems (Vattam, Helms, & Goel, 2008)(Baya & Leifer, 1996), and navigate across these levels by moving and iterating among them (Purcell & Gero, 1996). As a result of decomposing the design problem into levels, new sub-problems emerge, all of which must be solved and satisfied by the design outcome. Thus, architects seek to provide solutions for sets of sub-problems while remaining loyal to the original formulation proposed for the main design problem. This “moving” from the main design problem to sub-problems and among the various sub-problems, and then returning to the main design problem has been studied in architectural practice since Schön (1985, 1987) and Goel (1995), seminal works in the field. Simon (1962) and Chandrasekaran (1990) have also contributed to the understanding of such subdivision processes in design studies.

The legacy that these works left were the notion that architectural design, and most likely all kinds of design, advance in what Schön called “design moves,” which are “local experiments that contributes to the global experiment of re-framing the problem” (Schön, 1987), and that such moves obey a logic of what Goel referred to as “lateral and vertical transformations.” Goel’s lateral movements are those by which the designer moves from one idea to another idea, and vertical movement are those that allow the exploration of details in any idea (1995). However, these two complementary notions of design moves, while capture the notion of motion, movement, or navigation when advancing from one local experiment to another, do not capture the content that architects must deal with when they face a design problem formulation.

This research refers to such “local experiments” as “design episodes” (DEs) and seeks to reveal its content as well as the role that such units of content play in architectural formulation. As proposed here, DEs are discrete, perhaps unanticipated, units that consist of two components that move the design process forward: cognitive processes and drafting actions. Indeed, this research hypothesizes that design episodes are single units that bind cognitive processes and drafting actions performed by an agent, and by which design content regarding specific design ideas, issues, or features is elaborated. Such elaborations are explorations pursuing the definition and formulation of design problems, sub-problems, and constraints. Thus, and building on the ideas proposed by Schön and Goel, this research hypothesizes that such logic of movements governs the interplay of design episodes at two levels: among them and within each one of them. Figure 1 illustrates such logic.



**Figure 1: The logic of design movements, within and across design episodes.**

This capability to navigate across and within design episodes depends upon skills and knowledge, both talents that designers develop. Such talents allow designers, and architects among them, to drive design processes by representing design internally and externally. Internal representations conform a stock of knowledge that architects build, recall, and operate. External representations are constructed by architects who use skills such as sketching or modeling that they acquire from training.

The role of external representations in architectural design processes has been extensively studied (Kavakli & Gero, 2001; Menezes & Lawson, 2006; Suwa & Tversky, 1997), and several scholars have framed it as a kind of thinking (Gabriela Goldschmidt, 1991; Smithers, 2001). However, we remain far from understanding the role that internal representations of design knowledge play in framing architectural problems. It is indeed unknown how such internal representations interplay with the various external representations that architects

build when confronting a design task. Consequently, our understanding of the roles that such internal and external representations play for architectural formulation is far from being settled. It is also unknown how dividing a design problem into various levels, setting up design matters, and establishing design constraints drive design movements. Likewise, we are far from acquiring an understanding of the role, if any, that external representations play in building the architects' internal stock of design knowledge.

One reasonable assumption concerning this last issue might be that architects reorganize the way they frame and represent design in their minds by defining design constraints. If such a restructuring process occurs, architects not only develop internal representations of design knowledge but also create meaningful structures and concepts with which they evaluate and categorize units of content within their stock of knowledge. One question might be what the specific content of this stock of knowledge is. That is, which categories support this stock? In addition, how do architects use this stock when navigating within and across design episodes? And regarding the very nature of design episodes, another question should ask about the issue of the processes going on within design episodes and contributing to design moves.

Sketching an answer to these questions might shed light on how architects transform, recall, and use internal and external representations of design knowledge within and across design episodes. Such responses might also elucidate the manner in which these two types of representations conform the content of the stock of knowledge that architects bring to bear when formulating their designs. Finally, the answers to these various questions might reveal how the



interplay of internal and external representations drives design movements, which, as hypothesized, allows architects to frame and define design problems. While several fields of research investigate human cognition, these questions have only just begun to be addressed in the architectural design research literature, so our understanding is still limited and somewhat confusing.

## **1.2 Research Questions**

- 1) How are types of representations of architectural knowledge organized, related, and operated to formulate design problems?
- 2) Which procedures come into play in transforming ill-defined design problems into defined ones?
- 3) What is the content of the mental reservoir that provides the stock of knowledge and the procedures for attaining a goal definition in an early architectural design?
- 4) What are common cognitive strategies architects use to define design problems?

## **CHAPTER 2 FRAMEWORK**

The interest of this study is to understand the organization of architectural design processes, and particularly seeks to comprehend the way in which architects use procedural strategies as well as their stock of specific domain knowledge to formulate their early design. Consequently, this chapter presents the framework in which this research settles. Such a framework considers the revision of the nature of architectural problems, of models that scholars have proposed to understand design activity, and of studies that have contributed to our understanding the role that diagrams and sketches play in architectural formulation. This framework emerged from the revision of relevant studies from the design cognition literature, which also constitutes the main sources of information for the problem formulation of this research.

Thus, the chapter contains four sections, the first of which briefly discusses the nature of architectural problems which are open-ended. The seminal views presented include the ill-structured and wicked problem approaches, but also alternative and broader perspectives that contribute to the understanding of such a nature. The second section presents three theories about the organization of design processes. Throughout the revision of these theories, the section introduces the notion of mental models as complex representations of knowledge that gather various kinds of representations that architects manipulate, as well as the idea of procedural strategies, which bounds “know how and know that”. The third part of the chapter presents foundational and current knowledge regarding the use that architects make of diagrams and sketches when formulating their designs. Lastly,

the final section introduces the concept of “design episodes’ as constituent elements of the design process. The chapter ends with a summary that informs the key ideas leading to the experimental design and the analytical approach used in this research.

## **2.1 The nature of architectural design: Open-ended problems**

In the standard tasks encountered in architectural design, such as when the task is to create a form for a building, the criteria for what count as a successful solution are not assumed to be clearly understood. Instead, the formulation of the design problem and its solution are discovered together. This open-endedness is characteristic of many kinds design problems at large, but as I will discuss later, architectural design problems come with some additional complexity.

Research on design problems began in the sixties after Herbert Simon settled the differences between well-defined and ill-structured problems. In fact, he used examples of architectural design (Simon, 1969, 1973) to argue that the ill-structured condition of design problems stands on three points, which are the counterparts of similar subjects in well-structured problems:

1. While well-structured problems entail criteria for testing any solution, ill-structured problems completely lack such criteria.
2. While well-structured problems consist of “mechanizable processes” that allow the revision of any solution, ill-structured problems have no such mechanizable process.

3. While the “problem space” in a well-structured problem allows the representation of the initial state of the problem, the representation of the initial state of an ill-structured problem is vague and fuzzy.

In short, Simon stated that ill-structured problems such as design problems lack criteria for testing a solution, present non-mechanizable processes, and start from vague and fuzzy problem spaces.

To illustrate how these three conditions are present in architectural problems, we can imagine a very basic design task such as the design of a beam. Initially, we may not consider the design of a beam a design problem, but instead, a mechanical problem in the sense that the only task of an architect is to pick a material for the beam and perform the necessary structural calculations to guarantee that the beam will support a specific load. The length of the beam will be constricted by the distance between supporting elements. However, if we think in such a design process, we may find that the reality is far more complex, consisting of a number of possible starting points. While one architect may start by gathering known constraints such as the length of the beam and the load that should resist, another architect may start by selecting the material for the beam and evaluating different options, such as steel, wood, or concrete, according, for instance, to the visual integration within the context in which the beam will be located, let's say the main hall of a building. Thus, this architect may evaluate the election of the material by favoring aesthetic aspects over constructive constraints such as the length of the beam or the load that will support. A third architect may start by picturing if the image of the beam will be solid, will have perforations, or form a reticular structure. Independent of the starting point the architects choose,

at some point, they may think about how to attach the beam to an existing structure such as a wall, a slab, a pillar, or another beam. When contemplating how to attach the beam to the existing structure, the architects may consider and evaluate other possible solutions such as placing an extra pillar in the middle of the hall to add extra support for the beam. Later, they will also think about construction details—how to attach the beam to an existing structure, and even calculate the load of the supports for the beam. Further, if one of the architects decides on a concrete beam, he may calculate the section of the beam and the amount of steel needed. He may propose a specific design for the rebars, specify the type of concrete to be used, design the shoulders that will support the beam, evaluate the fixing methods for attaching the beam to the shoulders, and take into account structural considerations such as the use of seismic sways or other elements.

This example, which render a very basic and trivial problem in architectural design, illustrates the three conditions that ill-structured problems possess according to Simon. First, the architect needs to establish criteria for testing the outcomes that will emerge from the design decisions that will make when facing the several subproblems that emerge from the original design problem, such as the selection of a material for the beam, the method of attaching the beam to an existing structure, the aesthetic look and feel of the beam, or the necessary calculations to guarantee that the beam will support the structural requirements. None of those criteria are given with the problem given. In the same vein, if we think on how is that an architect performs the structural calculations needed to complete the design of the beam, we will notice that before

crunching the numbers, which we might think is a mechanizable process, the architect needs to define the material of the beam. In fact, the set of equations, the load that the beam may support, and even the beam's weight will vary if the beam is made of steel or concrete. Now, if the material is defined beforehand, the architect will need to run the calculations to guarantee that the beam meets the structural requirements. However, the outcomes of the calculations will tell if the beam will support, or not, the structural requirements, but hardly will inform if one design performs better than other. Thus, if the architect wants to measure the efficiency of the beam, he will need to establish different designs and compare them all. Thus, even mechanizable processes in design processes depends on not mechanizable design decisions such as the election of the material for the beam.

As the example illustrates, and as Simon stated, the initial formulation of design problems is always vague and unclear. In other words, circularity is a condition of design problems by which the formulation of the problem and the solution depends on each other. This condition of circularity is possible because, according to Simon, resources available to formulate the problem and the solution coexist inside the problem space<sup>1</sup>, which he defined as the space where all

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<sup>1</sup> Several scholars have devoted their attention to discussing and expanding the notion of “problem space”, which escapes the limits of this research. Interested readers can review the work of Cross & Dorst (Dorst & Cross, 2001), Dorst (Dorst, 2006), Goel (Vinod Goel, 1992, 1994), or Goldschmidt (Gabriela Goldschmidt, 1997) to name a few.

possible states of representations, or content, co-exist with possible operators for such content. The condition of circularity allows architects to formulate problems, to propose a solution, and then to evaluate the solution against the problem formulated to see if they match. If they do not match, architects propose another solution, change the criteria of the matching function, or even reformulate the problem. It is worth mentioning that Simon did not consider the “ill-structured” condition an absolute, but instead, a boundary between ill-structured and well-structured that was “*vague, fluid and not susceptible to formalization*” (1973, p. 181). Indeed, he suggested the possibility of changing the condition of a problem, or at least part of it, from ill-structured to structured, which is something that designers commonly do in the early stages of design processes.

Simon’s work is still a major reference and a framework for the study of the design process and designers cognition (Chai & Xiao, 2012). The influence of his postulates in design studies can be traced back to the first empirical studies of design processes by Eastman (1969, 1970). Later on, in the 1980’s, research by Akin (1986; 1982) continued to employ the same framework, as Goel (1992; 1992, 1994, 1995) did in the 1990’s. According to Dorst (2006), the early

symposia and workshops<sup>2</sup> on design thinking also contributed to nurturing Simon's view of design as a form of problem solving.

However, since the 1970s, scholars suggested a wider view of design that is not bound to a kind of problem solving. Rittel and Webber (1973), which are the most influential scholars advocating for such a view, claimed that design problems are “wicked problems” bound to planning problems. Rittel and Webber's vision of design claimed that planning differs from problem definition and goal formulation because it allows advancement in the design process even when a design goal has not been formulated. The authors named ten properties that distinguish plan making from problem-solving. However, among such properties, four are similar to Simon's condition for ill-structured problems. Architects know that to accurately define architectural problems, the following conditions must be satisfied: (1) architectural problems have no definitive formulation, (2) architectural problems have no stopping rule, (3) design solutions are either better or worse than others, but not true or false, and (4) every design problem is essentially unique. Thus, the link between these two views may be inherent to Simon's second condition in which he defined well-structured

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<sup>2</sup>DTRS symposia were organized at the University of Delf in the Netherlands, by N. Cross, K. Dorst, and N. Roozenburg in 1992 and 1994, and the Delf Protocols Workshop by N. Cross, K. Dorst, and H. Christiaans in the same location in 1996. These meetings attracted major attention from scholars studying designers' cognition and are frequently quoted today.



problems, or the notion of a mechanizable process. In fact, both mechanizable processes and planning demand a series of steps to attain a goal.

In the example of an architect designing a beam, each of the four properties mentioned above could apply. As stated, architects can start the design task from very different points, all equally valid. Consequently, no single starting point has been designated for the formulation of a design problem. Each architect determines when the design of the beam is complete and may even leave design decisions such as choosing the finishing and the color of the beam and detailing how to fix the beam to existing structure to others. Architects has this freedom because a design problem has no stopping rule. In addition, the solutions could be evaluated as more adequate than others, depending on the criteria. As Rittel and Webber asserted, the final design of the beam may be better or worse than other options, but not true or false. Lastly, although each beam problem must address similar constraints (e.g., a load that the beam will support, its length constrained by the distance between the pillars, a structure to which it will be attached, and so on), the solutions proposed by different architects will differ from each other. In other words, the design of each beam will be unique. In the context of this research, the approach of Rittel and Webber invites us to consider that the subproblems chosen and faced by different architects are responsible for (1) the design approach selected by those architects and (2) when they choose to stop designing an object.

So far, several empirical studies in design (Alexiou, Zamenopoulos, Johnson, & Gilbert, 2009; Björklund, 2013; Helms & Goel, 2014; Nikander, Liikkanen, & Laakso, 2014) have presented evidence supporting the approach

proposed by Rittel and Webber. Others that have discussed the “wicked approach” in theoretical terms are Buchanan (1992), Lloyd and Scott (1994), Goldschmidt (1997), Coyne (2005), Harfield (2007), and Farrell and Hooker (2013). Furthermore, others have suggested that the study by Rittel and Webber presented the first situated approach to design (Visser, 2006). These scholars catalogued their approach as an alternative to Simon’s postulates regarding the rationality behind his view (Coyne, 2005) and the linearity of steps involved in problem-solving (Buchanan, 1992).

Lastly, others have argued for shifting the focus from problem solving to broader aspects of the design process. Among them, Peponis (2005), who claimed that architectural problems are a matter of formulation, defined “formulation” as a process of discovery rather than one of solving a problem. Basadur, Ellspermann, and Evans (1994) claimed that problem generation and problem formulation precede problem-solving, and suggested that problem formulation is the phase in which a problem is defined, conceptualized, and structured. In this vein, Vattam, Helms, and Goel (2008) proposed a conceptual framework which presents compound design solutions as a consequence of analogical transfer and problem decomposition in the context of biological inspired design. Among the scholars that have advocated for wider frameworks are Visser (2006), who encouraged the study of design from a more situated perspective rather than a problem-solving approach, and Dorst (2006), who advocated for the consideration of the design context, which he viewed as the boundary between design discourse and design situation. Another perspective is offered by Cross, Naughton, and Walker who suggest a framework

complementary to problem solving which encompasses the difference between know-how and know-that in design practice (Cross, Naughton, & Walker, 1981).

In sum, current knowledge recognizes that the nature of design problems is complex and its study demands examination in a wider context, including not only how ill-defined problems are solved but also how problems are formulated. In architectural design, the formulation aspect is more important, since the goal is inherently a creative one—to come up with a new form. But further, even relatively small architectural design tasks are more complex than the design of a beam described above. The complexity comes from the fact that architectural design tasks require the co-ordination of several smaller sub-problems, several of which may by themselves be ill-structured. This raises questions about the procedures that architects can use to address design tasks. Most complex problems are solved by breaking them into sub-problems that can be addressed relatively independently, and the ill-structured nature of design problems can be addressed by working with provisional solutions and using analogical reasoning. But in architectural design tasks, since the final solution is weakly specified, or not at all, the specific sub-problems to be addressed are not obvious. Further the solution of one-subproblem depends upon the solution of another, but the problems are not hierarchically ordered. It is therefore somewhat of a puzzle how architects are able to plan and execute a design task—how sub-problems are defined and how the design process itself is structured. There has been some work on the structuring of design processes, though not much dedicated specifically to architectural tasks. In the following section, this work is reviewed.

## **2.2 Theories about the organization of design activity**

Schön (1987) outlined the condition of circularity of design problems as the interplay between “seeing, moving, seeing” that designers do while drafting. Since then, design processes have been understood as a cycle in which external representations such as diagrams and sketches activate internal representations of knowledge that recall other internal representations, which, in turn, are matched and evaluated against the sketch being drafted. Thus, the activation of mental representations supports the “seeing” operation while the “moving” part is the outcome of attention shifts among graphical elements and objects emerging in diagrams and sketches. In addition, Schön stated that “moving” from one representation being held in memory to another is what permits the simulation of experiments and evaluation in the design process. Moreover, he concluded that “the network of movements has many ramifications, and this complicates the problem, creating many implications that must be discovered and respected”. (p.67). The cycle proposed by Schön can be interpreted as "seeing," an internal representation activated by visual perception or visual imagery. “Moving” refers to the action of changing the focus of attention from a design issue to another, but it also could imply continual mental transformations of internal representations from one modality to another, for instance, from visual imagery to propositional representations. Then, “seeing” closes the loop, suggesting a revision or evaluation of the step that has just finished the interplay. In his study, Schön attempted to identify the mental mechanism that links the use of external representations such as sketches with internal representations of knowledge. His

interest, although centered on understanding the relationship between mental content and such external representations, did not dwell on their content.

Further, a mental model lies at the core of the notion of “seeing, moving, seeing”. Cognitive scientists refer to “mental models” as cognitive resources useful for this research because its richness captures and link various forms of knowledge representations. Craik (1943), the first to use the notion of mental models, suggested that through a process of reasoning, people encounter all kinds of situations by carrying out mental simulations and experiments on the internal models they develop. Since then, cognitive scientists have gone far beyond such a notion, proposing definitions and schemes that explain how is that these mental representations work. For instance, Johnson-Laird (1980) discussed various ways in which mental models are represented and used, and Gentner (1983) advocated for its use in the case of analogical reasoning. Equally important, Nersessian (2009) argued that reasoning with mental models forms the basis of scientific reasoning, stating that mental models facilitate reasoning about future states or situations. Her view on the role that mental models serve for scientific reasoning is analogous to some cognitive operations that architects perform when they simulate the behavior of a building’s components or people’s behavior in design processes (Yagmur-Kilimci, 2010). Further, architects make design decisions based on such analyses and evaluations, or in Nersessian words, their specific domain mental models. Building a bridge between cognitive sciences and design studies, Vattam, Helms, and Goel (2008) studied biological inspired design under similar assumptions about the role of domain specific mental models. However, Norman was the scholar that introduced (1988, 2013) the use of mental models

into the arena of design studies and assigned “predictive and explanatory power to understand interaction” (p. 7) among them. In architectural research, Foqué (1999, 2010) defined architectural design as a process of the transformation of information based on mental modeling, and Lawson (2001) claimed that both analog and symbolic internal representations might be stored and recalled from long-term memory by the observer when viewing a building or a spatial configuration. Lawson illustrated his idea using a very well-known example of architecture: the opera house of Sidney. According to Lawson (2001), Utzon's masterpiece carries "visual echoes of the sails of boats in the harbor" (p. 85).

Two scholars that expanded Schön's idea of movement in design processes are Vinod Goel and Gabriela Goldschmidt. Goel's seminal study (1995), after comparing the design processes of two architects, one of whom was cognitively impaired after a stroke, concluded that sketches play a key role in establishing the boundaries of ill-defined problems. His analysis suggested that the use of external representations such as diagrams and sketches allow what he called lateral and vertical transformations of ideas. For Goel, lateral transformations refer to the exploration of parallel ideas and vertical transformations to the exploration of ideas in depth, moving from general to specific issues in the design. According to Goel, with the use of external representations, ill-structured representations at hand prevent the premature crystallization of ideas and facilitate the lateral and vertical exploration of various solutions.

So far, this study has barely scratched the surface of the study of the content of specific units of knowledge and the role they play in the formulation of

architectural designs. Indeed, seminal work by Goldschmidt (1991) is the only known study that mentions such units of knowledge as a matter of architectural formulation. When analyzing Martin's Branch Library protocol, Goldschmidt indicated the "visibility and prominence of entrance, inside-outside relationship, hierarchical space adjacencies, site development" as design issues considered by one of the participants in her study. However, she specified neither what design issues meant nor what role they played in the design process.

A study by Keller and Keller (1996) in the field of cognitive anthropology shed some light on this enigma. Keller and Keller focused specifically on how a blacksmith organized and executed design task such as that of making a requested artifact. They argued that even when the requested artifact was a new design, the blacksmith's approach was to re-define the given artifact as a configuration of particular parts that could be visualized and shaped by known techniques. Once the shaping of individual items was determined, the overall task could be addressed by an overall plan of action, which determined the sequencing of the individual sub-tasks. They called such plans of action "Umbrella Plans" and defined them as the "mental representation of an ultimate goal for production and his [the designer's] associated general overview of the step-by-step procedures required to attain an end" (p. 90). Plans of action, they claim, operate as follows: In the case of a blacksmith fabricating a sword, even though he may not know what the final sword will look like, he knows that he must hammer one end of the sword into a point. Hence, various units of semantic content such as "sword," "blade," "iron," and "point," are bonded in the procedure of making the sword. The final shape thus was determined by the shape of the parts and what governed

the shape of the individual parts were specific techniques that were well known to the blacksmith. What is important to note here is that the final design was determined not so much by a freely imagined shape, but by component shapes constrained by known procedures. These procedures involved knowledge not only of the steps to be taken, but also propositional knowledge about materials, as well as visually and kinesthetically represented ideas that complement and interact with propositional knowledge. Keller and Keller's work therefore shows the clear connection between the complex embodied knowledge of the blacksmith designer, the designer's intentions, and the forms of the design outcomes.

Keller and Keller's work points to two issues directly relevant to this study. First it suggests that designers can solve ill-defined design problems by breaking them into tasks understood as well-defined problems. This is similar to Simon's suggestion, but their work shows its applicability to creative formal tasks as much as to problem solving. For the kind of tasks addressed by the blacksmith they speak of an umbrella plan organizing the entire activity, but the question remains whether architects while designing also operate with a pre-specified umbrella plan. The current study will address this question.

Second, their work suggests that one way to address the task of problem formulation—that is, of generating a formal solution without specified criteria for success, is to rely on specific learned procedures. Procedures are useful in this situation since they can be executed mechanically without specific goals in mind, and they can also bring to bear rich background knowledge that has both propositional and embodied elements. In the blacksmith's case, the procedures are embedded in the knowledge of techniques of the craft and the material (metal)



characteristic of the activity. Since the architect does not execute their designed buildings, do they have similar procedures available? The answer is that they do, that the procedures are embedded in the materials by which the design is described—drawings and models. The training of the architects includes specific procedures to generate solutions through activities such as diagramming or conceptual model making.

### **2.3 Diagrams and Representations**

One of such procedures is, for instance, a bubble diagram. In architectural design, sketching a bubble diagram is a procedural strategy that an architect uses to express the relationship among programmatic elements that graphically represent the architectural brief. Such diagrams are relatively shapeless, so they are not assuming any building form from the use of such representations. Although some architects sketch bubble diagrams by drawing various shapes such as circles or squares and labeling them according to the design brief, others may use only square shapes. However, the shapes that architects use to represent bubbles are not relevant because the principle governing the diagram is topological. Thus, all architects draw lines or arrows connecting shapes in the diagram to represent the connection of spaces as well as paths of circulation that the design proposal might have. In addition, each shape represents a room, and its size might correspond to the size of the room. Thus, shapes can be bigger or smaller, representing bigger or smaller rooms, but that is incidental. The key feature of the diagram is that permit the exploration of topological relationship among rooms listed in the brief.

From the above, we conclude that bubble diagrams are cognitive artifacts that allow architects to briefly translate a design problem into an external representation that entails various spaces. The design proposal should have along with options for connectivity, sizes of rooms (which architects refer as scale), and a general first approach to the layout of the building. Indeed, shapes in bubble diagrams can easily become structures, which, in turn, can become walls, and so on until a floorplan scheme emerges. Then, later on, architects can draw sections, define heights and levels, and evaluate such design outcomes and then return to the layout representation, move walls, and even go back and redraw parts of the bubble diagram, if necessary. Finally, we must also consider the possibility that architects might have other procedural strategies for transforming bubble diagrams into floor plan representations and that they also mix procedural strategies such as the use of bubble diagrams to draw site boundaries. The key point in this example is that architects know how to convert a design problem into a bubble diagram and eventually a floor plan. They know how to restate a given problem, a design brief, into a graphical representation of the problem, in this case, a bubble diagram. They not only know about but also develop procedures that promote this process. Thus, architects internalize such procedures that they recall later on and use to frame a variety of design problems.

By using procedural strategies, architects can represent design sub-problems graphically and translate design tasks given to them into something they can manipulate on paper. In other words, they use a strategy known to them, the bubble diagram, to solve a design brief (or a portion of it). Such a strategy consists of defining which spaces are clustered and which are separated. By using

procedural strategies, architects can divide any design problem into a set of sub-problems for which they may know procedures and steps, allowing them to solve that specific sub-problem.

Another example serves to integrate these ideas. For instance, an architect who knows nothing about Buddhism but commits to designing a Buddhist temple for the first time may agree to design it despite not understanding how such a temple works or how people behave and perform rites in such spaces. Intuitively, however, the architect is able to tackle this particular design using a bubble diagram. The use of a procedural strategy such as drawing bubble diagrams will help the architect to translate the brief into a graphical representation resembling a layout and to study various types of relationships among spaces specified in the architectural brief. In the same fashion, the architect knows how to approach the design of the site by drawing its contour and arrows to depict circulation patterns and then a set of design constraints that will slowly approach a design proposal. Possessing a stock of knowledge with semantic content and procedures for tackling sub-problems such as the architectural program or the site, the architect will start building up a narrative regarding the design task. Other architects, however, could approach such a project in a completely different way.

As the examples illustrate, architects develop procedural strategies that consist of a series of steps driven by internalized procedural representations of knowledge, and also possess a stock of declarative knowledge that allows design formulation while they engage in the use of procedural strategies, or “*in a conversation with the sketch*” as Schon stated (1996, p. 56).

Architectural drawings, including sketches and diagrams, have been referred to as “the language of design” (Schön, 1987). However, not all types of architectural drawings are the same. Diagrams and sketches are among the core type of drawings that architects use to formulate their designs and, long ago, scholars proposed that (1) types of representations were appropriate if they suited their intended purposes and (2) that what architects do with diagrams, sketches, and technical drawings such as facades, sections, or floor plans is not the same (Ö Akin & Weinel, 1982). Studies focusing on diagrams and sketches identified differences among architects’ use of diagrams and sketches and concluded that while diagrams are about symbols and concepts, sketches are about spatial form (Do, 2006). Scholars have also suggested that architectural drawings play different roles that range from a notational or symbolic to an imaginative function (Bafna, 2008). Studies on the roles and properties of shapes conforming diagrams have concluded that visualizing and envisioning relationships between shapes is what allows the emergence of new elements in design, which is the result of “seeing as and seen that” (Goldschmidt, 1991). That phenomenon, which Goldschmidt referred to as “the dialectic of sketching,” was also observed by Suwa and Tversky, who concluded that architects could “read- off” functional relationships and abstract features on the diagrams they create, inferring that such a property is what helps architects pursue design thoughts in more depth (Suwa and Tversky, 1997). Thus, scholars agree that such an ambiguous property of architectural diagrams is precisely what allows reinterpretation (Suwa, Tversky, Gero, & Purcell, 2001) as well as observations of things that are not there (Gabriela Goldschmidt, 1991; Suwa & Tversky, 1997).

While the studies mentioned above have focused on how architects use diagrams and sketches, the study of how people develop drawing skills has focused on identifying differences between the performance of experts and novices. Thus, seminal works on expertise produced by scholars in cognitive psychology (K. Anders Ericsson, 2014; K Anders Ericsson et al., 1993; K Anders Ericsson & Charness, 1994) have served to frame the differences between the role that diagrams and sketches play in experts' and novices' cognition, which have been extensively examined in design studies (Bilda & Gero, 2006; Cohen & Hegarty, 2007; Gonçalves, Cardoso, & Badke-Schaub, 2014; Kavakli, Sturt, & Gero, 2006; Suwa & Tversky, 1997) and art studies (Kozbelt, 2001; Pérez-Fabello & Campos, 2007; Seeley & Kozbelt, 2008). In general, the findings of these studies have asserted that expert designers use their capabilities of imagery more efficiently than novice designers in conceptual design processes (Kavakli & Gero, 2001), and that expert designers might not even need to sketch to formulate design proposals (Athavankar & Mukherjee, 2003; Bilda, Gero, & Purcell, 2006).

Much of the literature on drawings of the architects, therefore, has focused on how they function as external representations. However, one of the interests of this study is to focus on the drawings, specifically diagrams and sketches, as procedural artifacts—on how they can be used to generate a formal solution when the criteria for success or the end-state is not known.

Scholars in the design arena have studied the role that external representations play for problem solving in architectural design. Such inquiries have led researchers to conclude that procedural knowledge is indeed necessary to perform procedures and actions in order to solve problems (Jonassen, 2000).

Others also claim that procedural knowledge "describes and predicts actions or plans of actions" (Reffat & Gero, 1996, p. 254), and have suggested a relationship between development of procedural knowledge and expertise, particularly in the development of skills (Niedderer, 2007). Indeed, studies on the difference between the performance of experts and novices corroborate such findings and indicate that experts are more proficient than novices because they develop more procedural and domain-specific knowledge (Purcell & Gero 1998, Chan, 1990). Thus, this research will focus on understanding how the procedural qualities of diagrams and sketches contribute to formulation stages in architectural design.

## **2.4 Design Episodes**

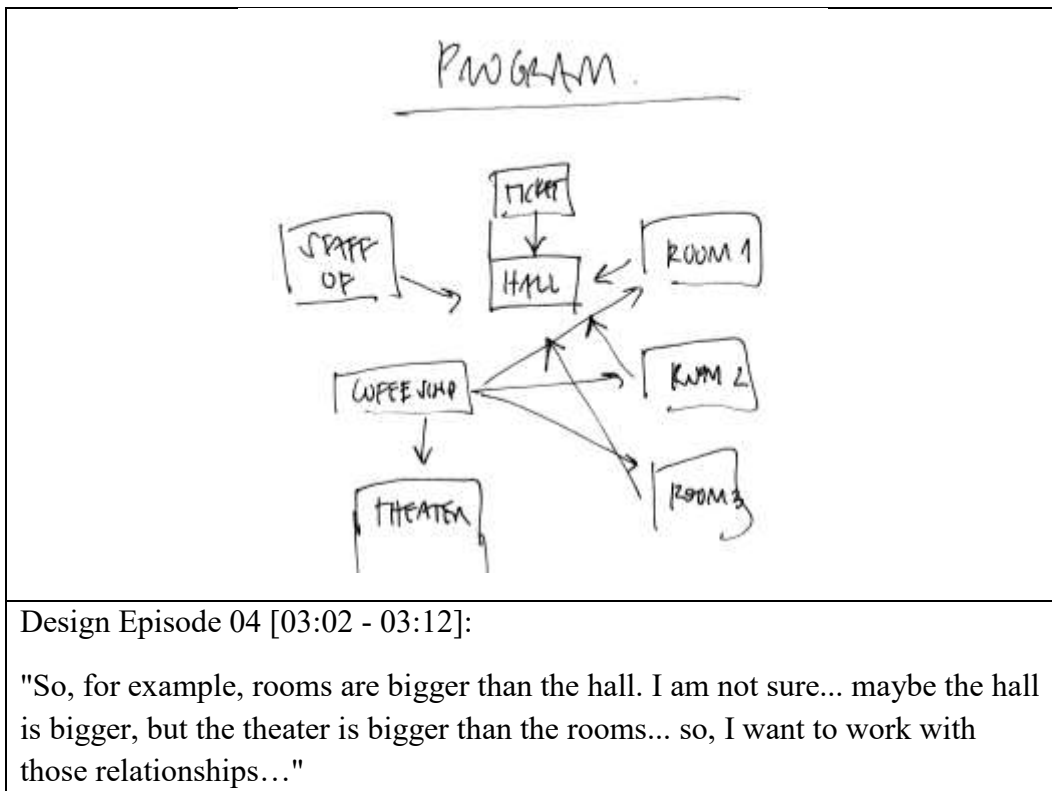
We have seen above that one source of complexity of the architectural design task is that it involves the solution of several sub-design tasks and that these sub-tasks may themselves be ill-structured and not organized hierarchically. A question that arose here was whether architects (like the blacksmiths described by Keller and Keller) work with well-defined umbrella plans for action, that organize the sub-problems into some kind of a sequence. One possible answer to this question may come from the observation that design activity of architects has an episodic character (Helms & Goel, 2014; Gero, 2006; Goel, 1995; Goldschmidt, 1991; Schön, 1985, 1987). But does the structure of this episodic movement correspond with the sub-problems that architects solve? Is each episode a matter of solving a specific sub-problem?

So far, few researchers have devoted effort specifically to design episodes (DEs) as a subject of inquiry, but several have adopted the idea of the DE in their

studies, mostly related to the idea of time frames identified for running protocol analyses. Among the scholars that have explicitly considered the role that DE may play for designers' cognition, Shön (1985, 1992) concluded that DEs are a consequence of designers' approaches to seeing and reasoning after analyzing the well-known protocol of Petra and Quist (1992). Goldschmidt (1991) noted that architects solve more design issues within short time frames than they do if they are reasoning generically about design (Gabriela Goldschmidt, 1991) (Gabriela Goldschmidt, 1991) (Gabriela Goldschmidt, 1991) (Gabriela Goldschmidt, 1991), and Lloyd, Lawson, and Scott (1995) inferred that, inside of DEs, designers experience and develop insight, silent thinking, and conjecture-analyses (Vattam et al., 2008). Likewise, Paton and Dorst (2011) contributed to the current understanding of DEs by identifying cycles for framing and reframing episodes after reviewing the initial stages of problem formulation.

Adding to such knowledge, this research defines “design episodes” (DEs) as time intervals in which architects' address specific design sub-problems. Thus, it is during these intervals that a DE exposes the content that captures architects' attention. The notion of DEs used in this research stands on the foundation of such previous studies and advances reasoning about specific design concerns, which determine the content of DEs. DEs' definition emerged in a previous study in which we observed how 14 architects, each with a unique background and level of expertise, consistently divided the design problem into sub-problems to tackle the design of a museum for the history of technology (Soza, 2011). The observation of architects' design processes led to the categorization of two groups according to the episodes they developed. The first group faced the design task by

formulating spatial layouts based on the use of bubble diagrams. We observed that architects' rationale while drawing bubble diagrams relied on their previous knowledge. For instance, they knew that a ticket office should be close to the entrance. Thus, an arrow connected the boxes representing the "ticket office" and the "entrance." Figure 2, below, presents the bubble diagram and the transcription of the record obtained from a DE developed by one of the architects that took part in the study.

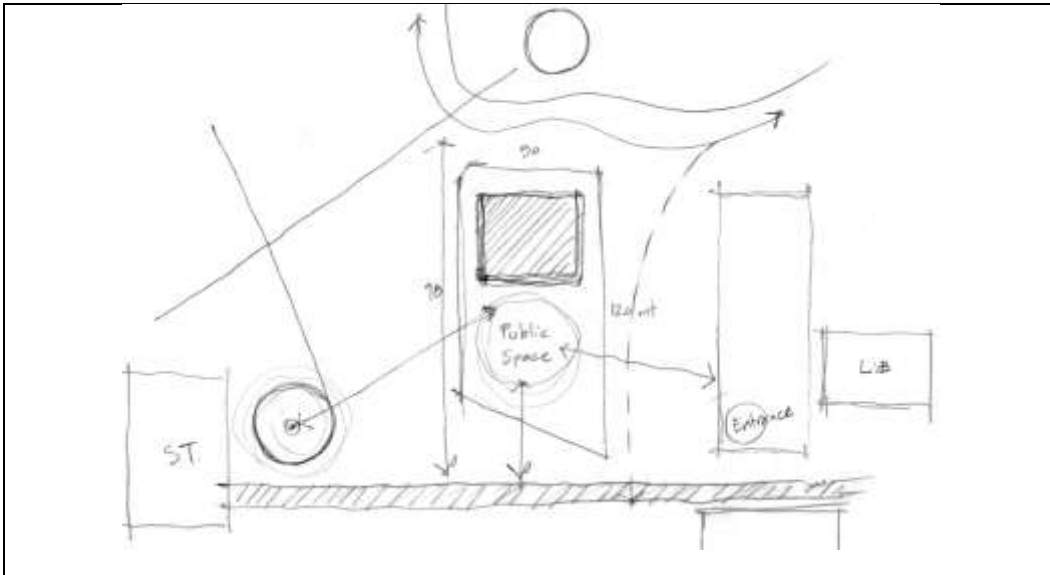


**Figure 2: Example of the use of a bubble diagram.**

The second group, by contrast, began the design task by analyzing the site and used four types of observations to frame the design problem. Figure 3 presents a DE in which an architect drew site issues and the transcription of the record obtained during the episode. The figure shows that the architect drew lines



and arrows depicting circulation patterns inside and around the site. The architect drew arrows while recalling views of the site and towards the site, and took into account natural conditions such as natural light and the path of the sun in the sky, the wind, and fluxes of natural ventilation, and the topography of the site.



Design Episode 01 [04:55 - 07:12]:

"Before I begin, I notice that this is a place I usually visit, almost daily, ahhh... it is also ahhh, circulation, a place with a lot of pedestrian circulation, which I think is quite important to define my design proposal.

So according to this, according to the ahhh, function of the building, that which supposes that is a building at least for the entire XXXXXXXXX community, is not ahhh, for just one single academic unit,

I think that the... the issue of the circulation can be used for defining a first proposal...

So, in that case... I think that my first diagram will consist on which I think are like the... main points and lines... that the circulation paths indicate in the... in the place... in the site...

as well as, ahhh, some lines insinuated by pedestrian circulation, and, I think it's pretty obvious that the round shapes got my attention..."

Figure 3: DE depicting site issues considered by an architect.

Thus, lines and arrows reflected the condition of the borders of the site, depicting functions of the constituent elements of the borders such as pathways, pedestrian circulations, and views from and towards the site. To approach the formulation of their designs, architects projected patterns of human movement as the dominant criterion while manipulating the other three criteria as if they were pieces of a puzzle. Participants recalled, twisted, and traded such criteria according to their design choices. Lastly, the pattern of cognitive movements that emerged from the study, regardless of whether volunteers started from an architectural program or a site, was the tendency for architects to move from general observations to specific details in their designs.

This dissertation stands on the fact that architects face design problems using a peculiar strategy that consists of dividing formulations of the design problem into sub-problems. As indicated earlier, several studies have adopted such a perspective. However, this inquiry differs from those studies in that sees DEs as the very units of analysis. Indeed, three questions that emerge from such a view are (1) are all the observed chunks of design activity DEs? (2) Do architects address one subproblem on each DE, or do they mix subproblems in DEs? (3) Is possible to isolate and identify specific units of architectural domain knowledge in DEs?

As stated, this study assumes that DEs expose episodes in which architects draft external representations that deal with mental content regarding design sub-problems. Further, the study hypothesizes that DEs correspond with design sub-problems and advance that DEs guide the activation the known procedures that allow architects to tackle design problems. Thus, instead of approaching the

formulation of the problem by defining design goals, the study predicts that architects use known procedural strategies to tackle particular subproblems rather than the main design problem. An important result of this hypothesis may be that by repeating procedural strategies for every new task they encounter, architects can tackle unknown design problems, refine their expertise in the use of the method, and expand their stock of knowledge.

## **2.4 Summary**

This chapter discussed four main topics to settle the framework of this dissertation. Such topics were the nature of architectural problem as open-ended problems, different models of organizing design, a revision of current knowledge about the role that diagrams and sketches play in architectural formulation, and design episodes as the main units of analyses for this inquiry. Thus, the first section reviewed the roots and limitations of the current understanding of ill-structured problems, which has been the dominant world view to set up design studies. In addition, this section also presented complimentary views that have expanded the scope of Simon's postulates. The second part discussed three models that sought to explain design activity. Such models presented and expanded the idea of design movements and propose a theory that links the use of mental content, skills and actions as resources used in design activity. Further, the section unfolded the idea of mental content by presenting mental models as rich cognitive resources that gather various kinds of mental and external representations. Thus, the section stated that this research does not consider the nature of the relationship between mental content and external processes a

dichotomy. Instead, it considers that mental content and drafting actions are strongly interconnected by the execution of procedures. Thus, the third part of the chapter present studies about the role that diagram, and sketches play in design processes. Further, this section presented and delves into the role that distributed and embodied cognition might play for design activity. Lastly, the chapter revealed design episodes, or DEs, as the key units of analysis that will inform this investigation. Thie section also presented two examples of different design episodes and a model explaining how, hipotetically, the components of DEs are bounded and contribute to the formulation of design problems and solutions. The next chapter presents the methods of study and the research design.

## **CHAPTER 3 METHODS OF STUDY**

This chapter presents the methods used in this research. Four major sections explain the criteria used for selecting the methods of study, the assumptions that were made, the research design, and the analyses and validation procedures used to obtain the conclusions of the study. Thus, the first part introduces the reasons for selecting protocol studies as the main method of analysis. It also presents a brief discussion of the weaknesses of this method and concerns that scholars have about it. After presenting the concerns that protocol studies rise as a research technique, the second part of the chapter present the assumptions made in this dissertation. The middle section presents a detailed revision of the research design, including criteria for selecting participants, determining the procedures, gathering data, designing the experiment, and assessing the design. The fourth part of the chapter explains the validation strategies and the quantitative and qualitative analyses involved in drafting plausible answers to the research questions. The chapter ends presenting a summary that gathers the key aspects concerning the adopted methods of study.

### **3.1 Criteria for Selecting Protocol Studies as the Main Method of Study**

The goal of the study was to discover what kind of procedures architects employ while designing and what cognitive structures underlie such processes. Such a goal lead to selecting the method of protocol study as the best way to approach the study.

Protocol studies have been conducted for more than 50 years to study designers' cognition since the first one reported in Eastman (1969). This popular research method has been recognized and validated for studies pertaining to designers' cognitive processes (Cross, Christiaans, & Dorst, 1996; Eastman, 2001). Indeed, the technique has significantly contributed to the current body of knowledge in the field of design cognition (Chai & Xiao, 2012; Jiang, 2009).

### 3.1.1 Protocol Studies and Its Problems

Although think-aloud protocols emerged as a method of psychological research in the 1920s (Cross et al., 1996), Allan Newell introduced protocol studies in the 1960s specifically for the purpose of studying human problem solving. He defined protocols as “time portions of recorded data [that capture] behavior” (Newell, 1966). Since then, the definition of protocols has remained relatively the same. To acquire such protocols, researchers present participants with a problem and ask them to think out loud while solving it, or they ask them to report their thinking after solving the problem. These two ways of gathering the verbalizations and actions of participants are commonly known as concurrent and retrospective reports. In both cases, the research team uses a tape recorder or a video camera to record the responses and sometimes the behavior of participants. Later on, while reviewing the recordings, they seek to understand what motivated the participants and what emerged from their verbalizations and behavior.

The way in which data of concurrent and retrospective reports are gathered is not trivial, and scholars have claimed that they are not the same. Whereas participants in concurrent reports speak their mind aloud while solving

tasks, those in retrospective reports explain what they did and why after the tasks (Ericsson & Simon, 1993). Arguments regarding the differences between the two types of reports and their weaknesses usually state very broadly that while real time verbalization of thinking may interfere with other cognitive functions, retrospective reports that rely on memory may be partial, and they are indeed challenging. Among other scholars, Chi (1997) offered a substantial discussion of such issues and proposed procedures and validation techniques for avoiding these various inconveniences. In addition, Ericsson and Simon showed that data gathered for running these type of analyses, usually verbal data, are “highly pertinent to and informative about subjects’ cognitive processes and memory structures” (Ericsson & Simon, 1993, p. 220).

Besides the way in which protocol studies collect data, since their early use, several scholars have exposed other concerns with the technique they apply to explain human cognition. Particularly in the arena of design studies, such apprehension stems mostly from doubts about the validity of the captured data in addition to the effects that reporting concurrent thought may have on participants’ thinking (Lloyd et al., 1995). Researchers have also argued that design processes involve the co-existence of verbal and non-verbal thinking (Jiang, 2009), but protocol studies may be not very suitable for capturing non-verbal information (Ömer Akin & Lin, 1995; Schön, 1983). Furthermore, some authors have suggested that design expertise is undeniably bound to visual thinking (Lawson, 1980, 1997; Schon & Wiggins, 1992) and that protocol studies fail to capture such a process. This view is aligned with that of Schön (1983), who claimed that

drawing and talking are parallel activities in the practice of designing, and together they make up the language of design.

Another example of a shortcoming of protocol analysis is that design crystallization lies in the interplay of sketching and thinking (Suwa & Tversky, 1997). Consequently, the issue of capturing and coding non-verbal information raises, at the least, concerns among scholars claiming that it is necessary to incorporate other means of capturing such non-verbal information. Researchers in the cognitive sciences and cognitive psychology have also exposed similar issues. Among them, Sternberg summarizing the strengths and the weaknesses of protocol studies, stated that the main asset of protocol studies is that it allows “access to introspective insight from participants’ point of view, which may be unavailable via other means” (Sternberg, 2005). On the other hand, the main weaknesses of protocol analyses are its “inability to report on processes occurring outside conscious awareness, data collection influencing cognitive process being reported, and possible discrepancies between actual cognition and recollected cognitive process and products” (Sternberg, 2005). Thus, while researchers have employed protocol studies as the main technique for building knowledge in the field of design cognition, the concerns mentioned above cannot be ignored. Therefore, to address such concerns, the next sections of this chapter declare the assumptions made in the study and present the research design and the methods of analyses used to draw the conclusions of the dissertation.



### **3.2 Assumptions of This Study**

A major assumption of this research is that observing the way in which architects formulate design problems, make design decisions, and treat design issues should reveal patterns, if any, in the way they use and build their stock of knowledge. Following the same vein, the study also assumes that the analytical approach used should reveal the set of procedural and semantic representations of knowledge that are assumed as key components of architect's stock of knowledge.

Regarding participants, this study assumes that master's students of architecture have enough experience to complete design tasks in a timely manner and deliver design outcomes appropriate to each design task.

The study assumed that participant's strong performance on both cognitive tests might predict good performance in design. Thus, participants with extraordinary analogy skills should produce more and better conceptual representations than subjects with poor analogy skills. Along the same vein, participants with high spatial aptitudes might be proficient at producing all kinds of external representations such as sketches, diagrams, floor plans, and sections. Indeed, and aligned with the previous assumption, participants would be expected to sketch accurate representations of both their design outcomes and intermediate stages of their design proposals while progressing on their design processes. In addition, their representations might show a high level of complexity, organization, and appeal, mirroring the vast content and processing of participants' stock of knowledge. Furthermore, whereas exceptional performance on both tests should expose a positive correlation with high productivity in proposing, testing, and drawing design ideas, lack of such correlation ought to

suggest failure of these premises, setting forth new questions for further research in the area.

In sum, the selection of both psychometric tests was based on the assumption that participants and architects with refined abilities in sketching visual representations and producing a large amount of architectural discourse should perform well, if not exceptionally well, on these two tests. However, correlations between the results of both tests and evaluations of the designs could shed light on the issue of whether such cognitive skills are at least in part if not completely responsible for design performance (in the eyes of the design judges).

The research also posits that differences in participants' level of experience was not important to outcomes. Indeed, a vast amount of research effort has been devoted to this issue, and the results of such inquiries have clearly indicated differences in the performance of novice and expert designers (Björklund, 2013; Kavakli, Sturt, & Gero, 2006). The research, however, does not attempt to study such differences.

This study intends to examine, at both an individual level and across participants, the interplay between procedural and semantic representations of participants' stock of knowledge that leads to design outcomes and determine if patterns arise from such interplay. Thus, the intent here is to identify and examine similarities and differences regarding design processes and to explain how architects, regardless of whether they are novices or experts, use declarative representations of knowledge and external representations such as diagrams and sketches to formulate their design proposals.

### **3.3 Research Design**

As mentioned previously, the investigation demanded an observational study of architects performing a design task in a controlled situation, along with a general overview of participants' skills and cognitive performance. Consequently, the research design considered as main element of the study a selected group of participants which were given a questionnaire, two psychometric tests, and four design tasks. Design tasks were the combination of two design briefs and two sites.

The data obtained included protocols of activity during design exercises, background information on the participants, a set of evaluations obtained from two expert designers, and results of two psychometric tests given to participants. The datasets were envisioned as follows: first, a general survey of participants for the purpose of gathering their background information; second, two psychometric tests that measured their cognitive abilities; and third, the set of four design tasks in which participants were observed engaging in design processes. The analysis stage consisted of one phase for grading design processes and another phase for analyzing design processes at different levels of granularity.

#### **3.3.1 Participants**

The participants were master's students attending the MArch program in the School of Architecture at the Georgia Institute of Technology. The criteria for selecting master's-level students stands on the supposition that they should have gained enough design studio experience to complete the four design tasks in a timely manner, delivering design outcomes for each one of such tasks. Thus,

fourteen participants were recruited by word of mouth, email, and advertisements as specified in the IRB protocol approved for this research (Appendix F). The selection of participants was random on the basis of first to arrive, first to be selected.

### 3.3.2 Procedures

This study required gathering data about architects facing psychometric tests and performing design processes. On the other hand, it also demanded an independent jury that graded their design processes in order to establish a base line for their design performance. Data pertaining to the design processes were gathered during two sessions for the purpose of preventing participants' cognitive fatigue, which would have degraded their performance and negatively impact the design outcomes. In the first session, approximately one hour long, each participant, following the requirements of the Office of Research Integrity Assurance at Georgia Institute of Technology, read and signed a consent form agreeing to take part in the study. Then they filled out a questionnaire with general information and completed two psychometric tests. In the second session, approximately 45 minutes long, each participant faced and solved four design tasks while thinking aloud. Participants had 15 minutes to study the set of

materials<sup>3</sup> depicting design briefs and then seven minutes to solve tasks one and two, and five minutes to solve tasks three and four. The medium in which they generated design outcomes was free-hand sketches. Participants were asked to draw floorplan diagrams, sections, views, and sketches and to write key words or meaningful sentences related to their design ideas. They also were told that the set of sketches should have all information required for others to understand their design proposals.

In sum, the procedures that participants followed were as follows:

First session (60 minutes long):

1. Read and signed the consent form agreeing to take part in the study
2. Filled out a questionnaire with general information.
3. Read the instructions for psychometric test number 1.
4. Answered psychometric test number 1
5. Read the instructions for psychometric test number 2.

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<sup>3</sup> The set of materials had two handouts with design assignments, photographs, and a schematic floorplan of each site, and a handout with the architectural program. Section 3.2.6 (Design tasks) presents the criteria used for defining both design assignments, which entailed designing a space for parties and events and another for a tea ceremony in traditional Japanese fashion. The design assignment handouts explained general information such as the meaning of the ceremonies and the basics about the rites: how people perform them, what they symbolize, and how they are commonly used in such occasions.

6. Answered psychometric test number 2.

7. Scheduled the second session.

Second session (45 minutes long):

1. Received an explanation of the think-aloud procedure.

2. Reviewed the material for the first design task.

3. Reviewed the site plan plus a set of photographs of the site.

4. Asked questions they had that were related to the design exercise.

5. Started the task.

6. Received a warning when one minute remained.

7. Told to stop working on the task.

8. Repeated Numbers 2 to 7 of the second design task.

9. Repeated Numbers 2 to 7 of the third design task.

10. Repeated Numbers 2 to 7 of the fourth design task.

The workflow defined for grading design processes consisted of asking two judges and professional architects with teaching experience to evaluate each design process based on an evaluation rubric<sup>4</sup> based on a Likert-type grading scale, ranging from 1 to 5, in which 1 was equivalent to “poor” and 5 to “very good.” Judges were instructed to work independently to avoid influencing one

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<sup>4</sup>Section 3.2.7, Independent Evaluation of Design Processes, presents and discusses the evaluation rubric.

another. The results of the grading process constituted a jury dataset for calculating scores, averages, and deviations. However, most importantly, the jury dataset allowed the study of correlations with results of the protocol analysis.

### 3.3.3 Data capture

Data capture was performed in the following fashion. In the first session and after signing the IRB form, architects answered a questionnaire and completed two psychometric tests. Appendices A and B contains copies of the questionnaire and psychometric tests. Participants recorded their responses on a sheet for each test. Hence, after the first session, each participant provided the researcher with a signed copy of the IRB form, a completed questionnaire, and two response sheets, one for each psychometric test.

In the second session, the data capture process consisted of video recordings of the participants' solving each design task. The recordings were carefully framed and captured their drawing processes, verbal utterances, and gestures. Consequently, the dataset obtained from each participant in the second session was a set of four audio and video recordings plus all of the participant's drawings, including diagrams and sketches, that each had created on each occasion. Figure 4 presents a photograph that captures the data of a session, the participant engaging in a design tasks, and the view of her that the video camera



**Figure 4. Frame from a video track showing the camera view.**

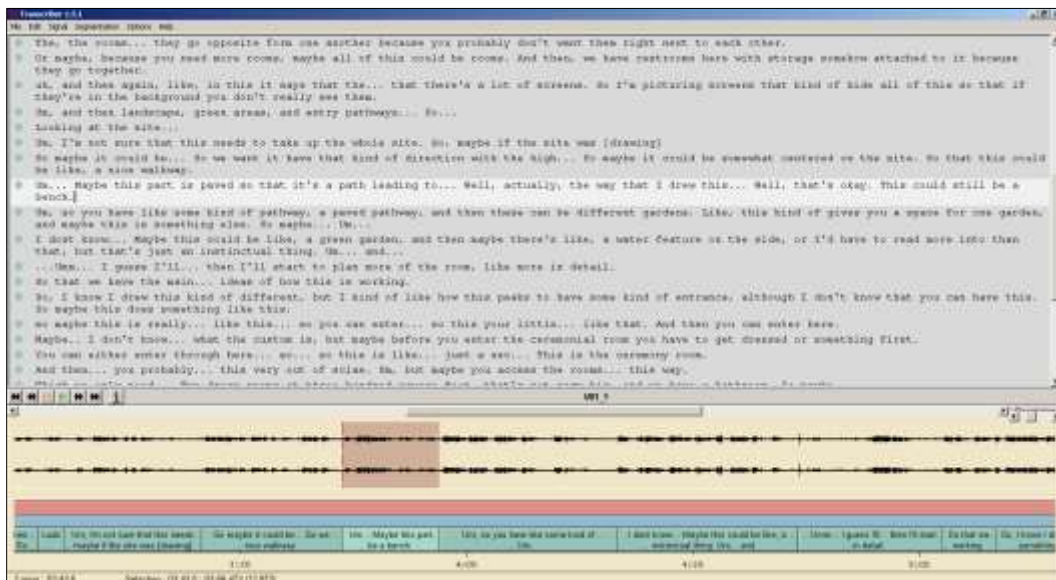
captured. The figure presents the setup, which included a video camera placed on a tripod slightly above her (neither in front of nor beside side) pointing towards the surface of the table in which she was working. The video camera recorded the voice of the participant and a detailed view of her actions while she sketched. Afterwards, the video files were transferred to a hard drive in separate folders, one per participant. All of the drawings that participants sketched were digitalized and stored on a hard drive using the same folder structure used for storing the video files. Finally, the spoken utterances on the recordings was transcribed and indexed along with the sketches that each participant produced.

### *3.3.3.1 Transcriptions*

The goal of the transcription process was to generate written documents containing participants' utterances. In this research a native speaker, a master student in architecture, helped with this task. With access to 56 audio and video



files showing participants' design processes, he was instructed to complete all the transcriptions of the verbal utterances of the participants. He used Transcriber 1.5.1, a software that allows manual annotation of utterances from audio files and saves resulting transcriptions in text format. Even though this software was developed for broadcast news recording, it is recognized as a useful research tool because of its features and ease of use. Figure 5 shows a screen capture of Transcriber. Using this tool, the transcribing assistant generated 56



**Figure 5. Screen capture of Transcriber 1.5.1**

text files, each of which was imported into word processor software for revision and for running the coding cycles.

### 3.3.4 Questionnaire

The questionnaire, a short survey consisting of only seven questions, was divided into three sections. The first requested general information such as age, gender, and number of years studying or practicing architectural design. Besides

collecting basic demographic information, the survey asked for years of experience in order to assess if such a variable has an impact on design performance. The second group of questions addressed participants' predilection for using specific tools and techniques such as free-hand sketches, drawing boards, and design software. The participants, who answered these questions "yes" or "no," had to choose between alternative tools and techniques when answering. The motivation behind asking these questions was to reveal if subjects felt confident using free-hand sketches as a design tool. We assumed that if subjects felt confident using sketches for designing, they would use their cognitive resources to solve the design task instead of directing part of their attentional resources towards the use of the design tool. Lastly, the third section of the questionnaire asked for participants' opinions regarding the role that ideas and sketches played in their design processes. We were interested in gaining a sense of how participants saw the relationship between the incubation of design ideas and the use of sketches as external representations of such ideas. Thus, questions seven and eight explore the role that participants assigned to ideas and sketches in their design processes.

The approach for analyzing these sets of answers was similar to the grounded theory developed by Glaser and Strauss (Glaser & Strauss, 1967). Following this method, experimenters, instead of starting from a formulation of hypotheses, seek emergent patterns in the data in order to build a theory. Thus, in their examination of the data, the researcher sought to identify emergent patterns, relationships, categories, concepts, and properties. After performing this search,

he marked and selected emerging issues, which finally coded based on emergent categories.

In the analysis of the fourteen written answers to each question, the researcher searched for keywords representing the basic idea inside of short answers (usually one phrase long) as well as main ideas exposed in answers containing several phrases and paragraphs. We completed both searching and coding functions as described by grounded theory for all the answers to questions seven and eight. If the answer contained a single phrase, then it was the only syntactic structure reviewed. Word repetition and word familiarity were used as criteria to build concepts, categories, and properties capturing and representing the key ideas in each answer. Word repetition exposed recurring terms that were the same or similar. Word familiarity rendered a meta-category that depicted all of the words gathered into a cluster subsumed to the meta-category that a term represented. For instance, the meta-category “Reasoning” emerged from the set of answers to question eight, which gathered run-on sentences and terms such as “Working out thought,” “Understanding,” “Supporting,” “Exploring,” “Discovering,” “Refining,” and “Manipulating.” As these words were mentioned by participants in contexts referring to, for instance, the mental manipulation of ideas, they were grouped into the meta-category of “Reasoning.”

The procedure for categorizing answers took place once for the fourteen answers to question seven and twice for the fourteen answers to question eight. An explanation for the difference in iterations was that while six key ideas emerged from answers to question seven, sixteen arose from coding the fourteen answers to question eight. However, a quick revision of these sixteen key ideas

demonstrated that several of them were associated with similar concepts and therefore could be grouped in clusters. We assumed that participants would provide qualitative data for seeking emerging issues regarding such role, and the goal of this section was to identify such issues. Appendix A contains a copy of the questionnaire administered to participants in session A.

### 3.3.5 Psychometric Tests

Participants completed two tests: the analogy test “A” and the spatial aptitude test (also known as that matrices test, or raven test). While the first measures semantic analogy capabilities, the second measures spatial skills, appreciation, and creativity. These two tests were applicable to this study, which hypothesized that architects are adept at developing, storing, recalling, and transforming semantic, visual, and spatial images, all of which constitute, in sum, their particular stock of knowledge. In other words, architects are expected to do well, if not excel, on these two tests, explanation of which follow.

#### *3.3.5.1 The Analogy Test A*

The analogy test A asks subjects to reason and select the most similar structural relationship between a sentence and a word chosen among various options. As commonly known, the analogy test measures the verbal aptitude of a test-taker, specifically general lexical skills. The test reveals the ability of an individual to build relationships between two subjects, a source and a target, in which reasoning is necessary to construct such a parallel relationship. The results of the test indicate two things: that the test-taker’s understand the meaning of words being asked, and that he or she is able to use such meanings effectively.

Certainly, strong performance on the test suggests an ability to compare, categorize, and transfer both the structural properties and meanings among concepts as well as the possession of good to excellent lexical skills (Carter, 2011).

The test consists of 20 “questions” in the form of phrases, and subjects must select a single word among a set of given options to complete the second part of an analogy of a structural relationship. An example follows:

*Night is to Evening as Winter is to:*

*Season, Snow, Autumn, Day, Spring*

*Answer: Autumn*

*Explanation: Night is immediately preceded by evening and winter is immediately preceded by autumn (Carter 2005).*

The highest score that participants can attain is twenty points (each question worth one point). Table 1 indicates performance levels, and the percentage of the population reaching such ratings according to the number of correct answers.

**Table 1: Semantic Analogy Test Scores.**

Score	% of population	Rating
19 – 20	Top 5%	Genius level
17 – 18	Top 10%	High expert
15 – 16	Top 30%	Expert
13 – 14	Top 40%	High average
11 – 12	Top 60%	Middle average
9 - 10	Bottom 40%	Low average

The test presented the 20 questions that participants had to solve in 20 minutes. The materials provided for answering the test were pencil and paper. Appendix B contained a copy of the questions and the answer sheet used to test the participants. The participants were expected to earn from 13 to 18 points, which would indicate strong proficiency in semantic analogy skills and therefore place them in the top 40% of the population regarding these abilities.

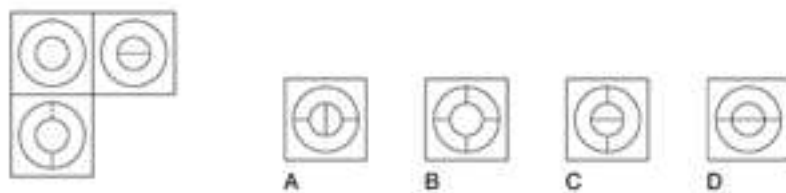
A computer screen showed questions, and time was configured to 1 minute per slide. However, participants who wished to finish faster pressed the bar space on the keyboard of the computer. In addition, we allowed them to go back and review previous questions as well as previous answers and change them. The experimenter monitored the overall time using a chronometer and warned participants when they had one minute left to finish the test. All of the participants completed the task within the 20-minute time limit.

#### *3.3.5.2 The spatial aptitude test*

The spatial aptitude test measures the ability a person has "to identify visual patterns and meaning from what appear at first glance random or very complex information" (Carter, 2005, p. 102). The full test contains five subsets from, one of which, the visual "odd one out" test, was administered to participants. Specifically, this subset measures an individual's appreciation of spatial design, logic, lateral thinking, and creativity. The test consists of fifteen questions containing five diagrams each, and participants must select the "odd one." An example of such oddness is that, for instance, a diagram consisting of an arrangement of circles, squares, and triangles, could be rotated 30 degrees

clockwise four out of five times whereas the fifth option is a reflection of the original arrangement instead of a rotation. The test expects subjects to notice the difference as a change in the visual pattern that drives the spatial relationships, ordering sequences, or metric relationships among diagrams by comparing all of them. An example depicting a typical question is shown below. Each correct answer is worth one point, and incorrect answers receive no points. Table 2 indicates the number of correct answers, the percentage of the population that answers correctly, and the ratings of proficiency levels.

*Which tile is missing?*



*Answer: C*

*Explanation: Looking across, one sees that a horizontal line is added to the small circle only. Looking down, one sees that a vertical line is added to the large circle only. The tile missing from the bottom right-hand corner should, therefore, contain both a horizontal line inside the small circle and a vertical line inside the large circle (Carter 2005).*

**Table 2: Matrix Test Scores**

Score	% of population	Rating
14 – 15	Top 5%	Genius level
12 – 13	Top 10%	High expert
10 – 11	Top 30%	Expert
8 – 9	Top 40%	High average
6 – 7	Top 60%	Middle average
4 - 5	Bottom 40%	Low average

The raven analogy test measures spatial aptitude and proficiency of creating meaning from nonverbal stimuli. The test consists of two components: the ability to make sense out of complexity and the ability to store and reproduce information. Top performance on the test indicates that subjects possess the ability to both manipulate representations in their minds and imagine a number of different results of such manipulations and see the big picture rather details or component parts (Carter, 2011).

Like we did for the Analogy Test A, we provided each participant with an answer sheet on which they recorded their answers. Appendix B contains a copy of the questions and the answer sheets. Participants were expected to score from 8 to 13 points, indicating spatial aptitude rating from “high average” to “high expert,” with all participants in the top 40% of the population or above.

Questions were presented on a computer screen and the exposition time was configured to one minute per slide. As they did on the Analogy Test A,



participants had the option to answer the questions faster by pressing the space bar on the keyboard of the computer. In addition, they were allowed to go back, review previous questions, and change their answers to questions if so desired. The experimenter monitored the overall time using a chronometer and informed participants when only one minute remained to complete the test. All of the participants completed the task within the time allotted.

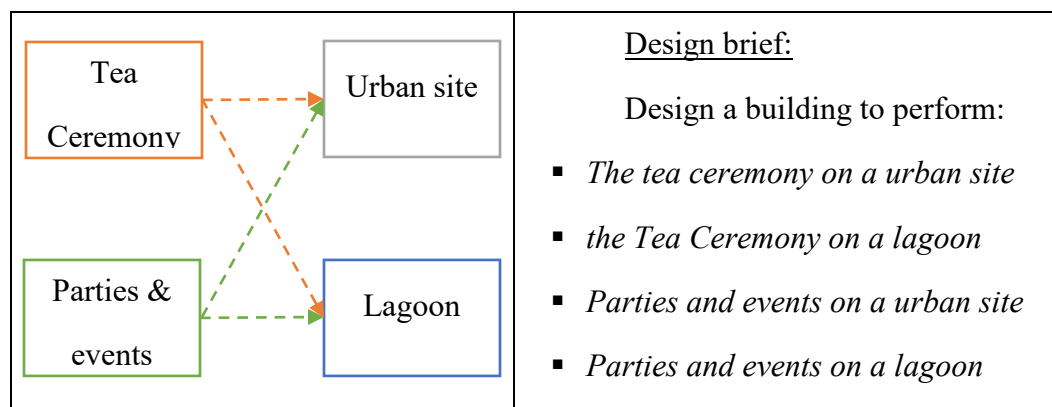
#### 3.3.6 Design Tasks

To explain how the authors defined the design tasks, this study revisited the findings of the pilot study, which suggested that architects rely primarily on two strategies to address architectural problems. In such a study was found that architects handle a repertoire of options for spatial organization which seems to drive design decisions regarding the overall design scheme. In addition, we also realize that architects rely of the analysis of the site strategy to approach the formulation of a design task. Indeed, such a strategy gathers four analysis tasks which allows architects to frame design problems. Such strategies are analyzing circulation patterns around and within the site, analyzing views from and towards the site, analyzing the borders of the site, and analyzing the natural conditions of the site (such as the topography of the site, its natural ventilation fluxes, or the pathway of the sun in the sky).

From the knowledge gained in the pilot study, we assume that these two strategies group representations that are stored in architects' stock of knowledge and that architects use them when facing design problems. Thus, the idea of isolating elements, that is, representations, of these clusters emerged. By isolating

such elements and observing how architects use them, we might be able to infer notions about the way architects operate their stock of knowledge. Therefore, such observations could lead to plausible answers concerning the first two hypotheses of the study.

Similar to the double dissociation principles used in neuroscience studies, this study used the two clusters of knowledge detected in the pilot study—the architectural program and site conditions—as variables in the study. However, one issue arose: It was not possible to ask architects to design a building by giving them an architectural program and a site or without telling them what the building would be. To tackle this problem, we decided to modify our double dissociation schema and replace the architectural program with a new element: the image and character of the building. Having a building image or character, a site, and an architectural program, architects were able to face design problems and propose design solutions. Removing the program would allow observation of participants handling representations that could be categorized as either a condition of the site or the purpose for a building. Hence, the schema presented two building aims and two sites, depicted in Figure 6.



**Figure 6: Combinations of architectural problem and site that participants had to face.**

The figure presents the combination of building image and character and sites and presents the four design tasks that emerged from each combination. It shows that participants had to design two buildings, and both had been designed twice, one for each of the two sites, which generated four design outcomes. The next section presents the criteria used for defining building image and character, sites, and the architectural program.

#### *3.3.6.1 Criteria for defining building image and character, site, and program*

The notions of site, architectural program, and architectural brief are key components of this study. Indeed, they dictate the way in which the protocol analysis was completed.

##### *The building brief*

Since the architectural program was fixed, we chose two building briefs that could function with exactly the same program. This requirement is easily met by a ceremonial building since the same architectural program can perform very different ceremonies. Thus, we defined a space in which parties and events take place, and in which a tea ceremony in the traditional Japanese fashion occurs. The rationale for selecting both ceremonies stemmed from a symbolic point of view: that they are open to various interpretations. It was assumed that architects would need to interpret each task, forcing them to define a vision of the building image and character in addition to articulating that vision with the site conditions and architectural program. Thus, participants had to design a space in which a tea

ceremony in the traditional Japanese fashion would take place and another in which parties and events would occur.

### *The sites*

Since the intention was to identify differences among the architects' stock of knowledge regarding site conditions, the study presented two very different sites. Site A was an urban setting located at the corner of West Peachtree Street and Arts Center Way. Site B was a natural scenario located by the lagoon in Piedmont Park. The hypothesis behind the selection of these two sites was that, regardless of their differences, they would trigger similar strategies of work by the participants.

Site A, the urban setting, is a relatively complex one. Each border, 17<sup>th</sup> St., Arts Center Way, and the south limit propose different spatial problems. Thus, the borders were problems that an experienced architect should have taken into account if working on this site. West Peachtree Street presents very dense traffic and high noise levels. Arts Center Way has a very small pathway on the north side before turning south and terminating on the east side of the site. In addition, the corner formed by West Peachtree Street and Arts Center Way presents a unique condition in which the space opens up toward the northwest, offering a great view in that direction. In addition, very tall buildings occupy most of the surrounding context—the corner of West Peachtree Street and Arts Center Way—and frame the view in the northeast direction, strengthening the condition of urban scenario. The traffic and the sensation of movement that captures observers' attention when they visit the site also augment the sensation of an

urban setting. The east side of the site presents a different story. After turning south, Arts Center Way slopes nearly 30 feet up to the level of the High Museum. Therefore, the topography of the site differs around 30 feet high among the highest point of Arts Center Way and the lower level of West Peachtree Street. The east side also presents, along the entire border, a grove of beautiful tall, old trees. Hence, the topography and the line of trees are features that the site also requires an architect to work with. Finally, the south border, which faces the MARTA station, has a massive block of concrete that marks the southern boundary of the site. The MARTA station represents both a natural access and exit of pedestrian traffic. Therefore, these two elements, the massive block of concrete and the circulation of pedestrian flow coming to and from the MARTA station are elements the participants had to take into account.

Site B, a natural setting located along the southeast edge of the lagoon in Piedmont Park also presents a challenging environment. The border condition offers possibilities for designing on the ground, along the border, or even over the water. The attractive scenery provides a unique perspective from which one can view and contemplate Atlanta's skyline from the park, surrounded by trees and the lagoon, isolated from traffic and noise, and accompanied by people exercising, walking by the pathway along the edge of the lake, and enjoying the natural setting.

Thus, while site A is akin to an urban island surrounded by a city, site B resembles the boundary between water and earth immersed in nature. Below, figures 7 to 10 present the plan views and photographs of both sites. Figure 7 shows the plan view of site A, the urban setting, and Figure 8 presents the main

view towards it, the corner of Seventeen St. and Arts Center Way. Figure 9 is the plan view of site B, the lake, and Figure 10 presents the view towards the skyline of Atlanta.



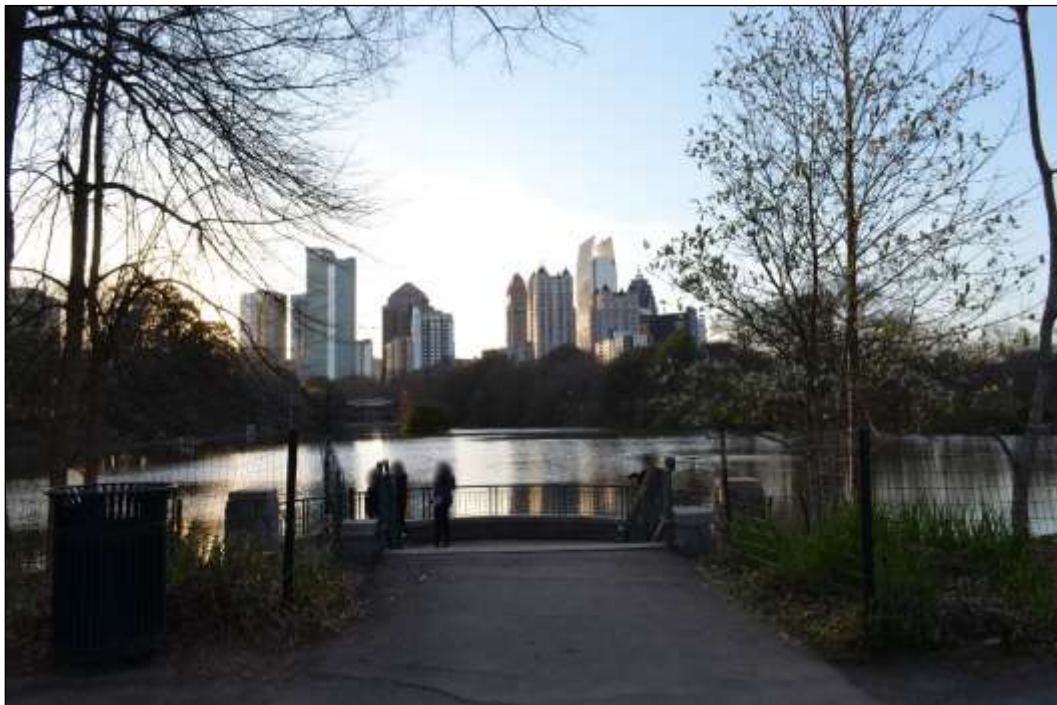
**Figure 7. Site A - Urban Setting. Image obtained from Google maps.**



**Figure 8. Site A - Urban Setting at West Peachtree Street and Arts Center Way.**



**Figure 9. Site B - Natural Setting. Image obtained from Google Maps.**



**Figure 10. Site B - Natural Setting. A view of the lagoon towards Atlanta skyline in Piedmont Park.**

### *The architectural program*

As stated, to fulfill the spatial requirements on both assignments, we proposed an extremely modest architectural program. It had to be general enough to match both assignments but simple enough to allow architects to reach a design solution within the time allotted. Hence, we proposed an entrance space, a ceremonial (main activity) space, private areas (functioning as administrative offices and such), restrooms, and green areas. Table 3 contains the architectural program.

**Table 3: Architectural program that participants had to solve for each task.**

An entrance space	200 Sq/ft
A ceremonial space	1000 Sq/ft
Private areas	200 Sq/ft
Restrooms	200 Sq/ft
Green areas	
TOTAL	1550 Sq/ft

The square footage for each space stated in Table 3 are average areas for these spaces. However, we told participants that modifications of the sizes of rooms and even uses for the rooms were welcome. The rationale for this instruction lay in the nature of architects' job, which allows them to modify an architectural program according to their personal interpretation of the assignment as well as their experience. Therefore, allowing them to introduce changes in the program was an opportunity to find patterns of how architects apply their interpretations. Such observations might lead to a clearer understanding of how architects frame design ideas regarding spatial arrangement.



#### 3.3.6.2 Time estimation for performing design tasks

As stated in the procedures sub-section, participants had 15 minutes to study the design assignments and sites, seven minutes to solve design tasks 1 and 2, and five minutes to solve tasks 3 and 4. Such a short time intended to avoid rumination time and to push participants to “jump into the design problem,” fixing their attention on whatever they considered the key features of solving each task.

Previously, to determine how much time participants needed to propose a design idea, we tested three-time frames with a volunteer: 10 minutes, 7 minutes, and 5 minutes. The volunteer, an architect with either years of experience in professional practice tackled the four design tasks. She reported that five minutes was not enough to propose a design idea while delivering a floor plan plus two or three sketches. Conversely, she reported that ten minutes was too much time even though it allowed the emergence and exploration of other design ideas and left extra time for exploring parts and details of her design proposal. Finally, she reported that seven minutes was enough time to deliver “napkin sketches” depicting her design proposal through various diagrams resembling rough floorplans, sections, facades, and even views of her design. With the results of this test in mind, we allotted seven minutes for participants to complete the first two tasks, and as the first test familiarized them with the assignment, the sites, and the architectural program, we allotted only five minutes to complete tasks three and four. The design outcomes produced by this participant were discarded since the key point of her participation was to test time frames.

### 3.3.7 Independent Evaluation of the Design Processes

As stated in the procedures sub-section (3.2.2), two reviewers, professional architects with more than 10 years of professional practice and experience teaching Design Studio, independently evaluated the design processes of the participants. To perform the evaluations, reviewers received a two-section rubric. The first section asked for general information: the judge number, participant number, and design task number. The second presented six dimensions and their definitions that judges were to grade. The dimensions, developed by Amabile (1982) as an assessment technique for measuring creativity, were creativity, novelty, aesthetic appeal, design sophistication, overall organization, and richness. However, this research redefined these dimensions so that they would be more familiar to judges. Thus, judges received the following definition for each concept:

- Creativity: the degree to which the design intent (i.e., building aim) of the participants, using their own subjective definition of originality, was original.
- Novelty: the degree to which the design itself showed formal innovation as result of novel ideas introduced in the design process.
- Aesthetic appeal: the degree to which sketches and diagrams were aesthetically appealing.
- Design sophistication: the level of sophistication shown by the design process, considering the number of issues that participants took into account while moving forward in their design processes.

- Overall organization: the degree to which the representations of design outcomes showed good functional organization.
- Richness: the number of issues (i.e., building aim, site, program, materials, construction issues, style, and others issues that might have emerged) that participants revealed in the design process.

Judges had to assign a single score to each dimension using a Likert-type scale with predefined values from one to five, one indicating “Poor” and five “Excellent.” To accomplish their task, judges received access to an electronic rubric and the 56 video files recorded while participants’ solved the design tasks. Electronic access was elected as medium of work for two reasons. First, considering that each judge was going to grade six dimensions for each design process, it was assumed that they would generate a considerable amount of data. Having the judges’ data already in electronic format would hasten posterior analyses and preclude the possibility of errors while transcribing the information from paper to digital format.

Another advantage of electronic access as a medium of work was that because judges had to watch the recordings of each design process to grade each dimension, the time required to complete the evaluation was a major concern for them. As each participant grades four design tasks—two in seven minutes and two in five minutes—the time required for viewing all the videos was a minimum of 5.6 hours. This time frame did not account for revisiting the data, for instance, replaying segments of a video, nor going back and forth with pauses between video segments when needed. Hence, we chose to give judges electronic access to digital video files so that they could work according to their personal agendas.

Thus, we organized the video files into 14 folders, from participant 01 to participant 14. Each folder contained four video files, each designated a participant number followed by the design task number, i.e.; P05\_1, P05\_2, P05\_3, and P05\_4. The 14 folders were uploaded to a web server with video-streaming capability, and the web server was configured to ask for a password to reproduce the videos. Judges received the hyperlink by email and a password to access and watch the videos. Finally, after the judges completed their evaluations, we erased the data from the web server.

### **3.4 Methods of Analysis**

The study gathers quantitative and qualitative methods of analyses which were applied at the different datasets: responses to the questionnaire, results of the psychometric tests, recordings of the design processes, and assessment of the designs. The first two datasets point to the internal validity of the research and seek to discard the effects that design expertise and differences in cognitive performance among participants might have had on the validity. The last two datasets were used to study the design episodes and their content and to calculate correlations between such outcomes and design performance.

#### **3.3.1 Quantitative Analysis**

With the requisite of drawing a baseline for observing design processes, we found it necessary to discard the effects that differences in expertise and cognitive skills play in designer performance. In this particular case, triangulation was considered a model formed by three datasets: one shaped by the responses to the questionnaire, the tests of cognition, and the evaluations of design processes.

The analysis involved identifying correlations among such datasets. Briefly, Table 4 presents and summarizes the quantitative analyses.

**Table 4: Summary of quantitative analyses.**

	Data set	Analysis target	Test
Questionnaire	Age, experience, and preferred design tool	Design expertise	Descriptive statistics; Correlations
Psychometric tests	Outcomes of the tests	Cognitive performance	Descriptive statistics; correlations
Design evaluations	Scores on the dimensions	Design expertise	Descriptive statistics; correlations

From the datasets shown in Table 4, we calculated descriptive statistics and used correlation tests to build evidence for reviewing whether or not performance in design was related to cognitive abilities and experience, that is, for drawing the baseline stated above.

In addition to identifying the correlations, we summarized the opinions of participants regarding their preferred tools for design in order to assure that they felt confident using sketches as the medium of work. We sought to build evidence for a claim that participants' felt comfortable and were proficient using sketches and that the use of such a technique did not demand additional cognitive resources, particularly attentional resources, which could have diminished their performance, as the work of some scholars have suggested (Bar-Eli, 2013; Bilda & Gero, 2007). Chapter 4 presents and discusses results that emerge from the quantitative analysis.

### 3.3.2 Qualitative Analysis

As stated, since the goal of the research was to explain the nature of the stock of knowledge and the hierarchical organization of particular strategies that architects apply when delineating early design problems, emerging as the best suitable option for addressing such a goal was protocol analysis. Hence, this section presents a revision of the way in which we completed such an analysis. The first sub-section explains the procedures for coding protocols, which followed Madeleine Chi's functional steps for *quantifying a qualitative analysis of verbal data* (1997) and combined such steps to the way in which design episodes (DEs), key units of analysis of the study, were sought. The subsequent sub-sections review the coding schemes used in the cycles of coding and explains how new coding concepts arose in the open-ended coding cycle.

#### *3.3.2.1 Coding protocols*

This study, which considered protocols analysis as an analytical stage in the study of design processes, adapted Michelene Chi's functional steps (1997) for coding protocols. Chi's functional steps depict a logical progression of eight stages that researchers must follow so that they ensure the validity of their studies by averting problems that protocol studies entail as a research technique (exposed in Section 3.1.1) as well as personal biases. Chi's method offers a mechanical approach to properly work through the datasets in each step while ensuring the verification and validity of the study. In short, these steps are reducing the data, segmenting the reduced protocols, developing a coding schema, operationalizing evidence while coding the protocols, depicting the mapped coding schema,

seeking patterns in the mapped schema, interpreting the patterns, and then repeating the entire cycle.

Reducing data is necessary because usually, after the process of transcription, recordings gathered during data capture become extensive and abundant written documents. Chi suggests two ways for reducing data: Researchers can randomly select portions of the data and work with such chunks, or they can do an initial cycle of coding (i.e., selecting areas of interest) and later perform new cycles of more detailed coding in the areas of interest previously detected. To do so, researchers must advance to the second step, which is segmenting the selected areas. Integral to this step is to identify units of analysis within verbal utterances. Chi points out that such units of analysis should emerge from the research questions.

Chi also advises that when segmenting selected areas, one must take into consideration four issues: granularity, correspondence, features, and searching. Granularity involves the length of the segment and reveals units of varying sizes, such as propositions, sentences, ideas, reasoning chains, paragraphs, or episodes. Correspondence is the operation through which researchers should match such segments with the variables of the study, which should have emerged from the research questions. Features, which rely on syntax and mechanics, allow assigning boundaries at various segments, separating semantic content from non-content. Finally, searching depicts a state in which participants generate self-explanations. Chi claims that by using this schema to segment protocols, researchers can identify occurrences and avoid an exhaustive segmentation of the protocols. Chi's third step of coding protocols is developing a coding schema, the

most critical part of her mechanics. She claims that the criteria for developing such schema rely solely and completely on the research questions. The next sub-sections will present in detail the coding schema developed and used in the study.

The fourth step of coding protocols is operationalizing evidence for coding. This step implies determining which segments constitute evidence for each category defined in the coding schema. The fifth step entails depicting the mapped schema, which provide a visual representation of the coding once it is complete. Such depictions can take several forms such as a diagram with links connecting nodes, which helps researchers to understand links, patterns, and connections that might exist inside and among datasets. Therefore, the fifth step is closely bound to the sixth step, seeking patterns in the mapped schemas. As stated, such visual representations provide a rich resource in which one explores the depth, shallowness, or connected of the various units of content, that is, knowledge representations, that the participants' used while performing the task presented by the research team.

The seventh step of Chi's coding protocols is interpreting such patterns and assuring their validity. Chi suggests completing this step by observing common operational mechanisms that architects use by grouping similar units of contents of knowledge they employ. In addition, to ensure validity in inferring such patterns, she recommends either testing these interpretations statistically or coding the data twice. The latter is a common procedure that researchers use and easily accomplish by asking two or more individuals to code portions of the data and calculating inter-rater reliability, the method used in this research and explained in sub-section 3.3.3. Finally, the last step of the protocol, which is



optional, consists of repeating the entire cycle. Researcher may have to perform this step if they wish to address additional research questions or recode the protocols at another grain size.

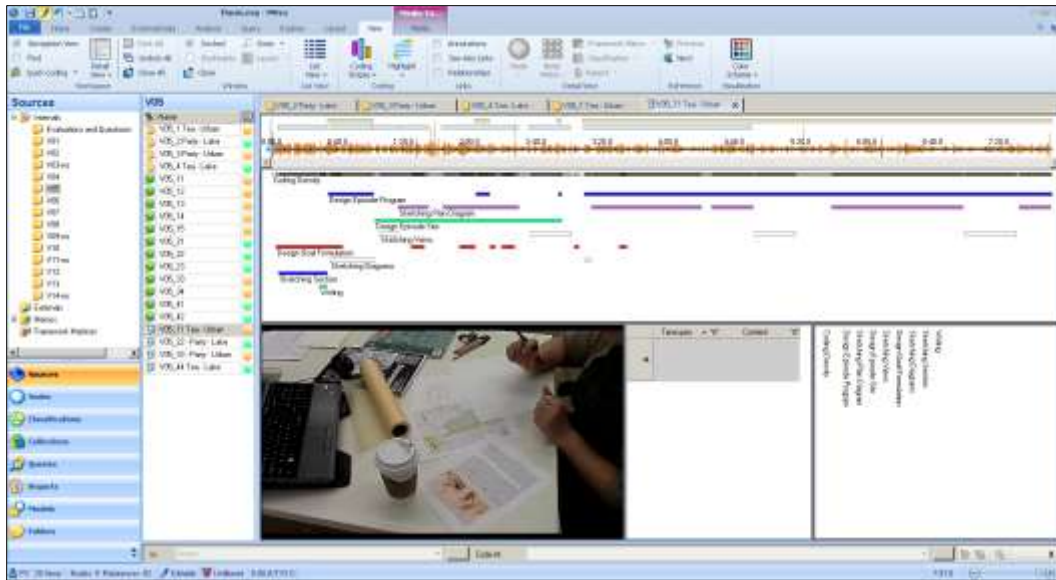
As stated, this research involved three cycles of coding. The goal of the first was to identify design and drafting episodes, and that of the second was to identify specific units of content, that is, declarative representations of architectural knowledge, used by participants within such design and drafting episodes. Thus, the first coding cycle consisted of coding all content recorded in each one of the 56 design processes. The main idea behind coding all of the data instead of reducing it, as Chi suggested, was to compare design processes at not only an individual level but also across participants and to study their correlations with design performance (according to judges' evaluation). In addition, the research design called for a clear depiction of all participants' design processes, which was suitable for studying differences among such processes, undertaking patterns and differences in the way participants faced these various design tasks, framed design problems, and used their stock of knowledge. Chapter 5 presents the results attained after performing the first cycle of coding.

To perform the second and third cycles of coding, three cases depicting high, middle, and low design performance according to the judges' evaluations were selected. Chapter 6 presents the results of these analyses.

The segmentation of protocols was completed through assessments of the recordings and marking the beginning and end of diagrams and design episodes. As explained in Chapter 2, diagrams episodes captured the time frame in which participants created various external representations, that is, diagrams, such as

floor plan diagrams, sections, bubble diagrams, and so on. This was done by selecting the time in which participants were engaged in creating specific diagrams, not the exact amount of time the pencil was on the sheet of paper. For instance, if a participant was sketching a floor plan diagram, stopped for a few seconds to talk about her thoughts, and then continued working on the diagram, the entire time was considered a continuous time frame and coded as a “floorplan”. Design episodes (DEs), on the other hand, took place within time frames in which participants engaged in specific tasks regarding the three main categories of design issues detected in a pilot study: those related to the site, to the architectural program, and to the formulation of design goals (Soza, 2011).

Completion of the first cycle of coding and the segmentation process involved the use of two datasets, the video recordings and the written transcriptions. To perform segmentation and coding, we used the qualitative content research tool (CAQDAS tool) Nvivo, version 10.0, which allows the segmentation and the coding of various types of data, including video, audio, and text files. The reason for segmenting and coding video files was to study the emergence of patterns regarding the amount of time participants engaged in the different episodes. Afterwards, the segmentation of the video files was used as a guide for coding the transcriptions with a purpose of exploring the content of the text by running search and query functions that Nvivo offers, which could provide support dealing with the nature of the stock of knowledge architects use for framing design problems.

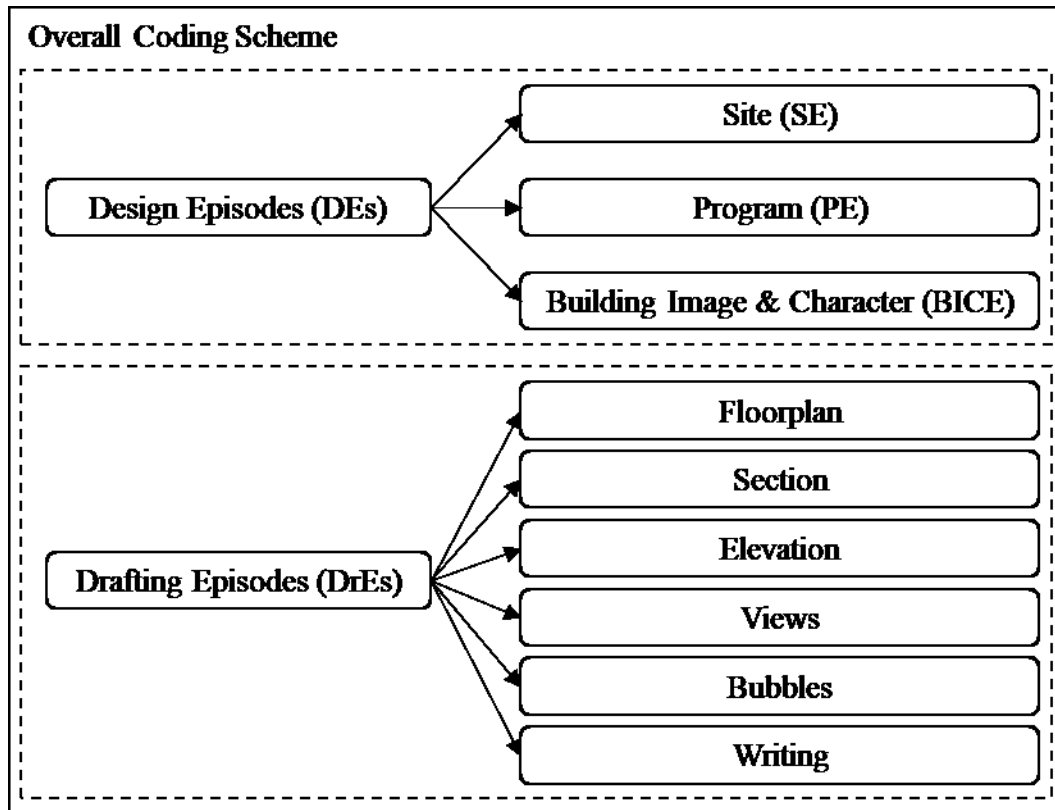


**Figure 11. Segmentation and first-cycle coding in Nvivo.**

Figure 11 depicts a screen capture of Nvivo, in which segmentation and coding of the video file were completed.

### *3.3.2.2 Master coding scheme*

This section presents the master coding scheme developed to perform the third step according to Chi's functional approach to analyzing verbal data. Based on a previous study (Soza, 2011), here it was proposed a two-level coding schema for running the protocol analysis. The two levels, depicted in Figure 12, were DEs (design episodes) and DrEs (drafting episodes).



**Figure 12. General coding scheme.**

DE categories (SE, PE, and BICE) were used to expose verbal utterances in which the main content being spoken out loud regards such matters. DrEs exposes time frames in which participants engaged in using specific kinds of diagrams such as floorplans, sections, facades, views, general diagrams, and writing or labeling.

The coding scheme states that SEs were those in which the participants examined site-related matters such as the topography of the site, the condition of its borders, patterns of circulation inside or around the site, views from and towards the site, and natural conditions of the site such as lighting or wind currents. PEs were those in which architects engaged in proposing and reviewing

alternatives of spatial organization for the assignments. Examples of PEs included proposing and testing a particular layout for the design problem, establishing associations or relationships among spaces, or altering the architectural brief by proposing new spaces or uses of spaces, or even deleting some of the specifications outlined in the design brief. The third main category, BICE, captured episodes in which participants focused on establishing a premise that they could use as major design constraint for addressing design moves and design decisions. Usually, BICE episodes emerge when architects try to define the “main design idea” or a “design concept” for guiding the design process. BICE episodes can relate to site or program issues as well as any another type of matter related to the design task. For instance, common examples of the formulating design goals are envisioning or recalling mental images, using analogies or metaphors triggered by the design task, perceiving issues from the site conditions, imagining possible uses for their design proposal, or any other idea that could arise and support the vision of a target toward which a design proposal might advance.

The most interesting condition of BICE episodes is that they function as anchors for fixing the first state of the design proposal. Therefore, content being treated within these episodes can either acquire the role of design constraints or become a goal of the design, indicating that they can be anchored to build design ideas upon them or that they can be a feasible path of exploration or become the main design goal to be reached. Thus, while the roots of BICE can be traced back to the nature of design problems, site and program episodes are findings recalled from previous research.

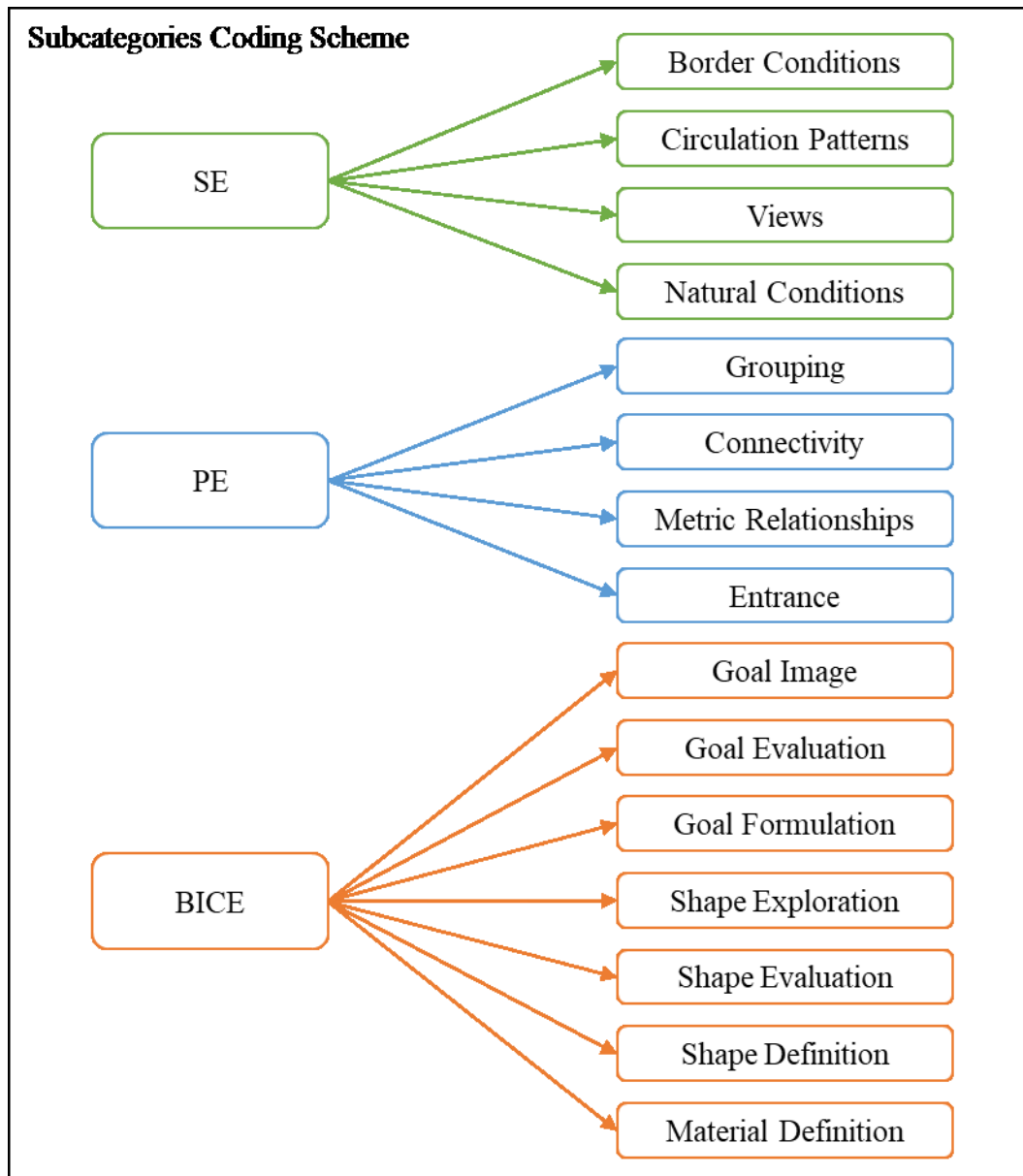
These six categories for drafting episodes matches what scholars in cognitive science call “external representations” (discussed in Chapter 2), emerge from what Schön referred to as “the language of design” (Schön, 1987). In architectural design, floorplan diagrams represent an orthogonal view from above the building. Architects use these representations to explore and depict possible spatial layouts; room arrangements, circulation zones, dimensions, and placement of spaces, as well as the location of entrances and exits. Sections represent a vertical cut across the building whose main function is to show the various levels of a building, its vertical circulations, and the vertical organization of spaces in multilevel buildings. Architects also use sections to depict the scale of internal spaces and to address issues regarding topographic conditions. Elevations are orthogonal views showing buildings seen from one side that is usually aligned to a compass direction (i.e., north façade, south façade, and so on). Elevations represent the external appearance of a building. Views are perspective representations of both interior spaces and exterior views of a building. The goal of such views is to show in advance how people will perceive and experience the building and its surroundings. Whereas floor plans, sections, and facades are two-dimensional representations, views are three-dimensional representations of the design. Unlike floorplan diagrams, bubble diagrams do not necessarily represent the building itself. Architects use them in a visual manner to explore and represent design issues and ideas. Finally, writing and labeling are mostly used to capture, through quick notes, sentences, and key words, meaningful points regarding design goals, constraints, or any other issues that architects may want to remember, recall, or reinforce in later stages of the design process. Writing helps

architects anchor their ideas and define constraints. Each of the above types of representations that architects commonly use allows specific goals, so they reveal the intentions of architects in their design process. Thus, analyzing the order in which architects use these types of diagrams and the content of DE they are addressing with such diagrams might expose design patterns that they follow in the design process.

In this study, segmenting and coding video files with this particular two-level schema revealed the correlations between DEs and DrEs. Thus, for instance, if a participant used a specific design strategy to face the four design tasks, the two-level scheme allowed envisioning such a strategy across design processes even though the outcomes of the design processes, and the processes themselves, differed. An example of the use of such a strategy would be the case of an architect that always start his design processes by using floorplan representations to analyze any site in which he will design any building. Indeed, this research assumes that the issues that participants preferred to address first were more meaningful than those they addressed later or those they did not address at all during the design exercises. As stated, observing if such strategies appear within design processes was one of the main concerns of this study.

### *3.3.2.3 Subordinate coding scheme*

Within episodes detected and coded using the master schema, statements were also coded according to subcategories that emerged in the pilot study.



**Figure 13: Coding schemes of design episodes**

Figure 13 presents such subcategories. For an SE (site episode), the subcategories present evidence of utterances in which participant explicitly talk about:

- Border conditions of the site



- Circulation patterns around or inside the site
- Views from and towards the site
- Natural conditions of the site such as:
  - Natural lightning and sun-pathway in the sky
  - Natural ventilation flows
  - Topographical conditions

For a PE (program episode), the sub-categories were the following:

- Grouping: Depicts topological relationships among spaces (grouping spaces). It may entail an evaluation of connectivity and metric relationships.
- Connectivity: Connectivity of spaces (circulation is more important than spaces)
- Metric relationships:
  - Placement: Decisions about the placement and orientation of spaces
  - Distance: Distances between spaces (separation)
  - Scale: Scale (Proportions of rooms and space between rooms)
- Entrance definition.

For BICE (building image and character episode), the sub-categories were the following:

- Goal image: imagining or recalling a visual representation that may or may not be related to the episode or sub-episode being tackled. It may include architectural elements such as walls, roofs, windows, doors or

passageways, or other elements. The goal image implies a visual representation and differs from goal formulation in that such an image is not yet a design goal, but one possible design goal, among others.

- Goal evaluation: evaluating goal images.
- Goal formulation: emerging from a goal image that has been evaluated against one or several aspects of the episode or sub-episode being tackled (e.g., imagery, user experience), but it is not clear if it carries intention. Goal formulation can be visual or propositional (semantic) in nature.
- Shape exploration: exploring shape with regard to "metric properties," "site borders," "semantic meaning," or other constraints.
- Shape evaluation: a comparison of shape and the representation of semantic issues and/or features.
- Shape definition: decision making about shapes. Such decisions stop exploration, formulation, or evaluation of shapes.
- Material Definition: mentioning material. They capture when participants refer to architectural elements or to the user experience and perception of such materials.

Building image and character episodes (BICEs) emerged as a new category in the coding process and revealed episodes in which participants engaged with imagining or evaluating a design goal during design processes. In addition, BICEs' subcategories included options to capture statements in which participants would think out loud about the shape of the building or would define materials for architectural elements, as architects commonly do in design processes.

Overall, it was expected that these sub-categories exposed the chains of reasoning used by participants to propose and solve design issues on each design task. Finally, it was also anticipated that other categories might have emerged during the analysis.

#### *3.3.2.4 Open ended coding*

Subcategories intended to reveal common declarative units of knowledge used by participants along and across design processes. For instance, the category of “views” applies to utterances that describe views from the building site toward a certain direction or an object and from anywhere toward the building. Thus, views can be recalled and coded in utterances revealing the intention of a designer to connect an interior space with an outdoor space. However, although such utterances should be coded as “views,” the code unit does not capture the aim of the designer, which was to connect two spaces in this example visually. As the example reveals, the coding schemes proposed and used in the study did not capture all of the design issues that participants dealt with at any specific time. This concern prompted a need for a new cycle of coding using an open coding approach, complementary to the coding schemes used in the study. Design issues (DIs) emerged as a result of the open coding process.

Ep	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi	bj	bk	bl	bm	bn	bo	bp	bq	br	bs	bt	bu	bv	bw	bx	by	bz	ca	cb	cc	cd	ce	cf	cg	ch	ci	cj	ck	cl	cm	cn	co	cp	cq	cr	cs	ct	cu	cv	cw	cx	cy	cz	da	db	dc	dd	de	df	dg	dh	di	dj	dk	dl	dm	dn	do	dp	dq	dr	ds	dt	du	dv	dw	dx	dy	dz	ea	eb	ec	ed	ee	ef	eg	eh	ei	ej	ek	el	em	en	eo	ep	eq	er	es	et	eu	ev	ew	ex	ey	ez	fa	fb	fc	fd	fe	ff	fg	fh	fi	fj	fk	fl	fm	fn	fo	fp	fq	fr	fs	ft	fu	fv	fw	fx	fy	fz	ga	gb	gc	gd	ge	gf	gg	gh	gi	gj	gk	gl	gm	gn	go	gp	gq	gr	gs	gt	gu	gv	gw	gx	gy	gz	ha	hb	hc	hd	he	hf	hg	hh	hi	hj	hk	hl	hm	hn	ho	hp	hq	hr	hs	ht	hu	hv	hw	hx	hy	hz	ia	ib	ic	id	ie	if	ig	ih	ii	ij	ik	il	im	in	io	ip	iq	ir	is	it	iu	iv	iw	ix	iy	iz	ja	jb	jc	jd	je	jf	jj	jk	jl	jm	jn	jo	jp	jq	jr	js	jt	ju	jv	jw	jx	ky	kz	la	lb	lc	ld	le	lf	lg	lh	li	lj	lk	ll	lm	ln	lo	lp	lq	lr	ls	lt	lu	lv	lw	lx	ly	lz	ma	mb	mc	md	me	mf	mg	mh	mi	mj	mk	ml	mn	mo	mp	mq	mr	ms	mt	mu	mv	mw	mx	my	mz	na	nb	nc	nd	ne	nf	ng	nh	ni	nj	nk	nl	nm	nn	no	np	nq	nr	ns	nt	nu	nv	nw	nx	ny	nz	oa	ob	oc	od	oe	of	og	oh	oi	oj	ok	ol	om	on	oo	op	oq	or	os	ot	ou	ov	ow	ox	oy	oz	pa	pb	pc	pd	pe	pf	pg	ph	pi	pj	pk	pl	pm	pn	po	pp	pq	pr	ps	pt	pu	pv	pw	px	py	pz	qa	qb	qc	qd	qe	qf	qg	qh	qi	qj	qk	ql	qm	qn	qo	qp	qq	qr	qs	qt	qu	qv	qw	qx	qy	qz	ra	rb	rc	rd	re	rf	rg	rh	ri	rj	rk	rl	rm	rn	ro	rp	rq	rr	rs	rt	ru	rv	rw	rx	ry	rz	sa	sb	sc	sd	se	sf	sg	sh	si	sj	sk	sl	sm	sn	so	sp	sq	sr	ss	st	su	sv	sw	sx	sy	sz	ta	tb	tc	td	te	tf	tg	th	ti	tj	tk	tl	tm	tn	to	tp	tq	tr	ts	tt	tu	tv	tw	tx	ty	tz	ua	ub	uc	ud	ue	uf	ug	uh	ui	uj	uk	ul	um	un	uo	up	uq	ur	us	ut	uu	uv	uw	ux	uy	uz	va	vb	vc	vd	ve	vf	vg	vh	vi	vj	vk	vl	vm	vn	vo	vp	vq	vr	vs	vt	vu	vv	vw	wx	wy	wz	xa	xb	xc	xd	xe	xf	yg	yh	yi	yj	yk	yl	ym	yn	yo	yp	yq	yr	ys	yt	yu	yv	yw	yx	yy	yz	za	zb	zc	zd	ze	zf	zg	zh	zi	zj	zk	zl	zm	zn	zo	zp	zq	zr	zs	zt	zu	zv	zw	zx	zy	zz	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi
Ep	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi	bj	bk	bl	bm	bn	bo	bp	bq	br	bs	bt	bu	bv	bw	bx	by	bz	ca	cb	cc	cd	ce	cf	cg	ch	ci	cj	ck	cl	cm	cn	co	cp	cq	cr	cs	ct	cu	cv	cw	cx	cy	cz	da	db	dc	dd	de	df	dg	dh	di	dj	dk	dl	dm	dn	do	dp	dq	dr	ds	dt	du	dv	dw	dx	dy	dz	ea	eb	ec	ed	ee	ef	eg	eh	ei	ej	ek	el	em	en	eo	ep	eq	er	es	et	eu	ev	ew	ex	ey	ez	fa	fb	fc	fd	fe	ff	fg	fh	fi	fj	fk	fl	fm	fn	fo	fp	fq	fr	fs	ft	fu	fv	fw	fx	fy	fz	ga	gb	gc	gd	ge	gf	gg	gh	gi	gj	gk	gl	gm	gn	go	gp	gq	gr	gs	gt	gu	gv	gw	gx	gy	gz	ha	hb	hc	hd	he	hf	hg	hh	hi	hj	hk	hl	hm	hn	ho	hp	hq	hr	hs	ht	hu	hv	hw	hx	hy	hz	ia	ib	ic	id	ie	if	ig	ih	ii	ij	ik	il	im	in	io	ip	iq	ir	is	it	iu	iv	iw	ix	iy	iz	ja	jb	jc	jd	je	jf	jj	jk	jl	jm	jn	jo	jp	jq	jr	js	jt	ju	jv	jw	jx	ky	kz	la	lb	lc	ld	le	lf	lg	lh	li	lj	lk	ll	lm	ln	lo	lp	lq	lr	ls	lt	lu	lv	lw	lx	ly	lz	ma	mb	mc	md	me	mf	mg	mh	mi	mj	mk	ml	mn	mo	mp	mq	mr	ms	mt	mu	mv	mw	mx	my	mz	na	nb	nc	nd	ne	nf	ng	nh	ni	nj	nk	nl	nm	nn	no	np	nq	nr	ns	nt	nu	nv	nw	nx	ny	nz	oa	ob	oc	od	oe	of	og	oh	oi	oj	ok	ol	om	on	oo	op	oq	or	os	ot	ou	ov	ow	ox	oy	oz	pa	pb	pc	pd	pe	pf	pg	ph	pi	pj	pk	pl	pm	pn	po	pp	pq	pr	ps	pt	pu	pv	pw	px	py	pz	qa	qb	qc	qd	qe	qf	qg	qh	qi	qj	qk	ql	qm	qn	qo	qp	qq	qr	qs	qt	qu	qv	qw	qx	qy	qz	ra	rb	rc	rd	re	rf	rg	rh	ri	rj	rk	rl	rm	rn	ro	rp	rq	rr	rs	rt	ru	rv	rw	rx	ry	rz	sa	sb	sc	sd	se	sf	sg	sh	si	sj	sk	sl	sm	sn	so	sp	sq	sr	ss	st	su	sv	sw	sx	sy	sz	ta	tb	tc	td	te	tf	tg	th	ti	tj	tk	tl	tm	tn	to	tp	tq	tr	ts	tt	tu	tv	tw	tx	ty	tz	ua	ub	uc	ud	ue	uf	ug	uh	ui	uj	uk	ul	um	un	uo	up	uq	ur	us	ut	uu	uv	uw	ux	uy	uz	va	vb	vc	vd	ve	vf	vg	vh	vi	vj	vk	vl	vm	vn	vo	vp	vq	vr	vs	vt	vu	vv	vw	wx	wy	wz	xa	xb	xc	xd	xe	xf	yg	yh	yi	yj	yk	yl	ym	yn	yo	yp	yq	yr	ys	yt	yu	yv	yw	yx	yy	yz	za	zb	zc	zd	ze	zf	zg	zh	zi	zj	zk	zl	zm	zn	zo	zp	zq	zr	zs	zt	zu	zv	zw	zx	zy	zz	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi
Ep	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi	bj	bk	bl	bm	bn	bo	bp	bq	br	bs	bt	bu	bv	bw	bx	by	bz	ca	cb	cc	cd	ce	cf	cg	ch	ci	cj	ck	cl	cm	cn	co	cp	cq	cr	cs	ct	cu	cv	cw	cx	cy	cz	da	db	dc	dd	de	df	dg	dh	di	dj	dk	dl	dm	dn	do	dp	dq	dr	ds	dt	du	dv	dw	dx	dy	dz	ea	eb	ec	ed	ee	ef	eg	eh	ei	ej	ek	el	em	en	eo	ep	eq	er	es	et	eu	ev	ew	ex	ey	ez	fa	fb	fc	fd	fe	ff	fg	fh	fi	fj	fk	fl	fm	fn	fo	fp	fq	fr	fs	ft	fu	fv	fw	fx	fy	fz	ga	gb	gc	gd	ge	gf	gg	gh	gi	gj	gk	gl	gm	gn	go	gp	gq	gr	gs	gt	gu	gv	gw	gx	gy	gz	ha	hb	hc	hd	he	hf	hg	hh	hi	hj	hk	hl	hm	hn	ho	hp	hq	hr	hs	ht	hu	hv	hw	hx	hy	hz	ia	ib	ic	id	ie	if	ig	ih	ii	ij	ik	il	im	in	io	ip	iq	ir	is	it	iu	iv	iw	ix	iy	iz	ja	jb	jc	jd	je	jf	jj	jk	jl	jm	jn	jo	jp	jq	jr	js	jt	ju	jv	jw	jx	ky	kz	la	lb	lc	ld	le	lf	lg	lh	li	lj	lk	ll	lm	ln	lo	lp	lq	lr	ls	lt	lu	lv	lw	lx	ly	lz	ma	mb	mc	md	me	mf	mg	mh	mi	mj	mk	ml	mn	mo	mp	mq	mr	ms	mt	mu	mv	mw	mx	my	mz	na	nb	nc	nd	ne	nf	ng	nh	ni	nj	nk	nl	nm	nn	no	np	nq	nr	ns	nt	nu	nv	nw	nx	ny	nz	oa	ob	oc	od	oe	of	og	oh	oi	oj	ok	ol	om	on	oo	op	oq	or	os	ot	ou	ov	ow	ox	oy	oz	pa	pb	pc	pd	pe	pf	pg	ph	pi	pj	pk	pl	pm	pn	po	pp	pq	pr	ps	pt	pu	pv	pw	px	py	pz	qa	qb	qc	qd	qe	qf	qg	qh	qi	qj	qk	ql	qm	qn	qo	qp	qq	qr	qs	qt	qu	qv	qw	qx	qy	qz	ra	rb	rc	rd	re	rf	rg	rh	ri	rj	rk	rl	rm	rn	ro	rp	rq	rr	rs	rt	ru	rv	rw	rx	ry	rz	sa	sb	sc	sd	se	sf	sg	sh	si	sj	sk	sl	sm	sn	so	sp	sq	sr	ss	st	su	sv	sw	sx	sy	sz	ta	tb	tc	td	te	tf	tg	th	ti	tj	tk	tl	tm	tn	to	tp	tq	tr	ts	tt	tu	tv	tw	tx	ty	tz	ua	ub	uc	ud	ue	uf	ug	uh	ui	uj	uk	ul	um	un	uo	up	uq	ur	us	ut	uu	uv	uw	ux	uy	uz	va	vb	vc	vd	ve	vf	vg	vh	vi	vj	vk	vl	vm	vn	vo	vp	vq	vr	vs	vt	vu	vv	vw	wx	wy	wz	xa	xb	xc	xd	xe	xf	yg	yh	yi	yj	yk	yl	ym	yn	yo	yp	yq	yr	ys	yt	yu	yv	yw	yx	yy	yz	za	zb	zc	zd	ze	zf	zg	zh	zi	zj	zk	zl	zm	zn	zo	zp	zq	zr	zs	zt	zu	zv	zw	zx	zy	zz	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi
Ep	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao	ap	aq	ar	as	at	au	av	aw	ax	ay	az	ba	bb	bc	bd	be	bf	bg	bh	bi	bj	bk	bl	bm	bn	bo	bp	bq	br	bs	bt	bu	bv	bw	bx	by	bz	ca	cb	cc	cd	ce	cf	cg	ch	ci	cj	ck	cl	cm	cn	co	cp	cq	cr	cs	ct	cu	cv																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											

**Figure 14. Screenshot captured during the second cycle of coding.**

DIs emerged from coding important keywords highlighted and selected from utterances. Such keywords capture the aim, or intent, that participants were working on achieving at any particular time. Figure 14 shows a screen capture of the second cycle of the completed coding process. In the figure, columns A and K indicate if the episode coded in the first cycle of coding was an SE, a PE, or a BICE. Green indicates that the utterance has been coded as an SE, blue a PE, and orange a BICE. Column C contains the overall transcription, already divided into utterances. Column D presents the codes used to classify each utterance, and column E contains the keywords of the utterances in column C. Column F groups several utterances used to define an emergent DI as a result of the open coding process. Column G lists the type of diagram that a participant was working on and column H the specific trace or graphical token made for each utterance. Empty spaces indicate that no trace was drafted during the utterance. Finally, column I indicates the meaning of traces. For instance, a single line could represent a wall, a path, the border of the site, and so on.

Six design processes were selected to perform the third cycle of coding using this template. As a result, as Figure 14 shows, the scheme of analyses exposed the interwoven nature of arguments given by participants during episodes.

### 3.3.3 Validity

To ensure internal validity of the coding procedure, we relied on two common strategies, triangulation and inter-rater reliability.

Triangulation is technique that consist on combining datasets and methods of analyses to study a single phenomenon and allows the research team to view the datasets from various perspectives (Neuman, 2006). In this research such an approach to guaranty internal validity rest on comparing data gathered from questionnaire, results of the psychometric tests, scores of design processes assigned by the judges, and results of the protocol analyses.

Similarly, inter-rater reliability guarantees the validity of a research by correlating the ratings of two or more raters (Whitley, 1996). This research used such calculations to ensure agreement between the judges' grading of the design processes, already explained in subsection 3.2.7, and between researchers' coding DEs. After receiving a coding guide containing definitions and samples, two doctoral students who were familiar with these methods coded 12 design tasks each, which then served to perform inter-rater reliability calculations. The agreement factor reached was 0.72.

### **3.5 Summary**

This chapter, in three major sections, exposed the rationale behind selecting protocol analysis as the main method of study, explained the research design, and the methods of analyses and validations techniques considered to examine the data obtained in the experimental sessions.

Thus, the first part presented a brief historical account on the development of protocol analysis as a technique to study human cognition and highlighted the importance that its use has had in the field of design studies. The section also

discussed the problems the technique presents, and the assumption made in the study regarding its use as the main method of analysis and data gathering.

The second part presented a detailed description of the research design and the criteria for selecting participants. After describing the procedures used to guide the experiment and gathered data, this section reviewed the different dataset that were collected, and the considerations taken into account to design the main experiment and to assess design outcomes.

The last part of the chapter focused on explaining the methods of analyses with special interest on describing the coding procedures, the design of the coding schemes, and validation strategies used to guarantee impartiality and consistent results. Overall, the chapter presented how design processes of participants were reviewed using protocol analysis techniques and the coding schemes used to perform such analyses.

## CHAPTER 4 EXPERIMENTAL OUTCOMES

This chapter contains three sections. The first summarizes the outcomes of the questionnaire administered to participants. The second presents the results of both psychometric tests, and the third presents the results of the analysis of the independent judges' evaluations of the design processes. The chapter ends with a discussion of issues that emerged from a review of the three datasets. The discussion focuses explicitly on the role that the experience of participants might have played in their performance.

### 4.1 Profiles of the Participants

#### 4.1.1 General Information Collected

According to the research design presented in Chapter 3, fourteen participants, seven males and seven females, took part in this data collection. The participants answered the questionnaire at the beginning of session A. One female participant did not answer the questions about her age, but for all others, the mean was 26.8 and the mode 24. The age range was 17 years, including an outlier, 40 years old, and six years if the outlier is disregarded. Participants' experience in architectural design ranged from one to eleven years, with a mean and mode of six years. Table 5 presents a summary of these results.

**Table 5: Summary of results for participants' ages and years of experience.**

	Range	Mean	Mode
Age	17	24.8	24
Years of experience	10	6	6



The sample was small and representative of the population of students registered in the Master of Architecture Program at Georgia Tech.

#### 4.1.2 Preferred medium of work

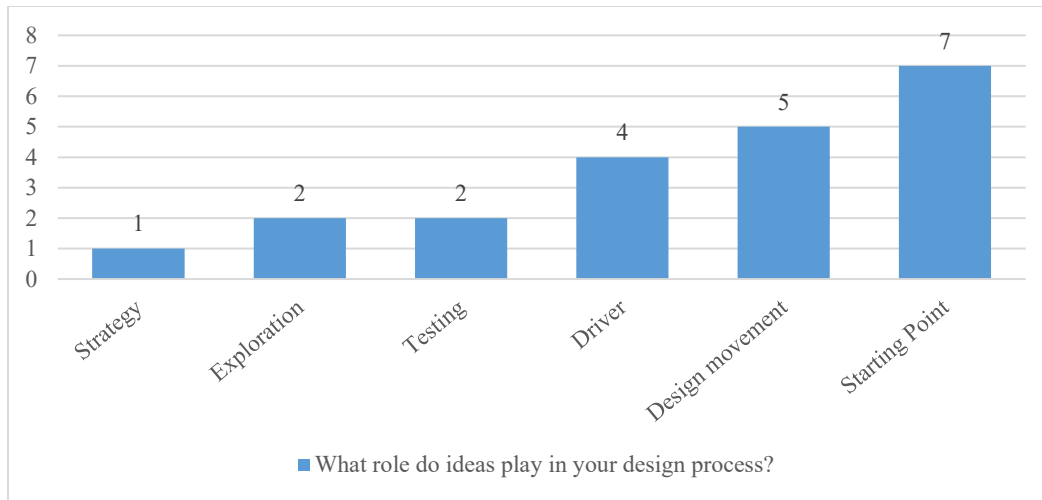
The questionnaire asked for participants' preference regarding the use of design tools. Such information was collected in three questions:

- Do you use sketches as a design tool?
- Do you use a drafting board as a design tool?
- Do you use computers as a design tool?

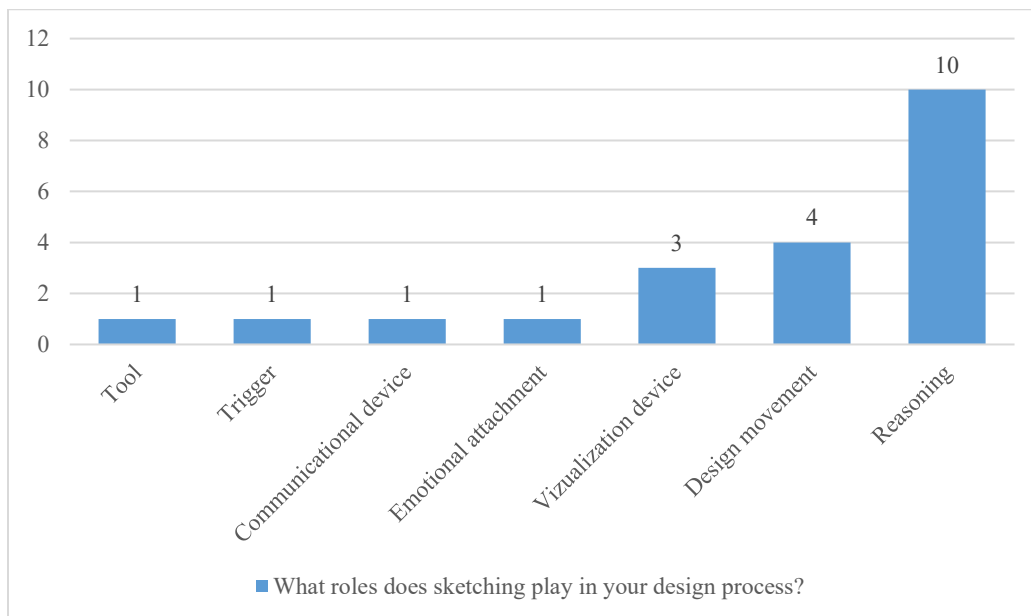
These questions provided a general overview of participants' confidence and expertise in using sketches, particularly since the experimental design allowed only sketches as the medium of work during the design tasks. The responses of all of the participants showed that they used both sketches and computers as design tools, and six responded that they also used a drafting board. Such results support the assumption of participants' confidence using sketches and validates the research design decision of restricting the medium of work to drafting activities.

#### 4.1.3 The Roles of Ideas and Sketching in the Design Process

Six key ideas emerged from the analysis of participants' answers to the question about the role that ideas play in the design process. Likewise, seven major ideas emerged after analyzing their answers to the question about the role that architects assign to sketching while designing. Figures 15 and 16 present the number of responses regarding the key ideas for each question.



**Figure 15: Participants' view of the role of ideas in the design process.**



**Figure 16: Participants' view of the role of sketches in the design process.**

Figure 15, which shows participants' opinions about the role of ideas in the design process, indicates that about half (7) reported that ideas were the starting point, and many (5) saw ideas as moving the process of design. Only one or two participants reported other roles such as testing, exploring solutions, and

developing design strategies. The notion of strategy matches the role of an idea to that of a plan or method that must be followed if a designer is to reach the (design) goal. Hence, as this notion is similar to guidance, it was clustered with “the main driver.” Thus, building on participants’ opinions, the role that ideas play in design processes was as the starting point that guides design advancement, and the later as a device that allows testing and exploration. While the first two categories suggest the existence of different states that evolve, the second two concepts suggest evaluation and examination of such states. Of course, to test or explore design solutions, such entities must exist first, meaning that they must have been defined beforehand.

Participants consider sketches as a tool, a trigger, a communication device, a visualization device, something that triggers emotional attachment, that push design movements, and that favors reasoning processes. Besides obvious outcomes such as a tool, a communication device, and a visualization device, it is worth mentioning that participants also view sketches as devices that trigger the generation of new ideas in design processes and as artifacts with which they engage at an emotional level. Thus, participants consider sketches as cognitive devices, and such a role has been thoroughly studied and well documented in the literature (Gabriela Goldschmidt, 1991; Menezes & Lawson, 2006; Purcell & Gero, 1998; Smithers, 2001; Suwa & Tversky, 1997).

A common issue that emerged in both sets of responses was the role that ideas and sketches play in driving “design movements.” This outcome, extremely pertinent to this research, emerged after adding up the six times that participants mentioned the role of ideas and the five times they mentioned that of sketches,

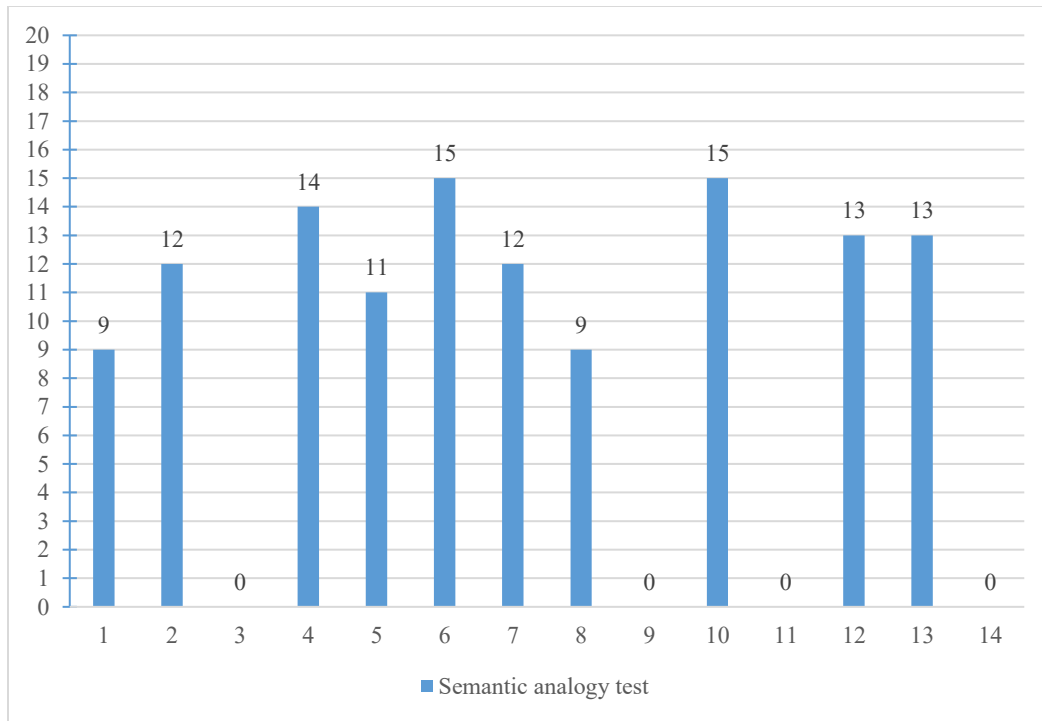
suggesting that participants assign similar roles to both ideas and sketches in moving forward the design process. Moreover, since this outcome was the second most common that participants bring to the table regarding the roles of ideas and sketches, it is not naive to propose that architects assign the same value to ideas and sketches as driving forces moving the design process forward. In other words, after analyzing the set of answers, is possible to infer that participants were clear about the centrality of sketching to their individual design activities and in agreement about its primary use as a reasoning device.

## **4.2 Results of Psychometric tests**

As described in the methods section, participants completed two psychometric tests: the Verbal Aptitude Analogy A test and the Raven Progressive Matrices test. Out of the 14 participants, ten completed the Verbal Aptitude test and eleven the Raven test. One participant withdrew his participation from the Verbal Aptitude test because English was his second language, and he did not feel confident taking the test. However, he completed the Raven test. Three participants (numbers 3, 9, and 10) did not take the tests.

### **4.2.1 Results of the Verbal Aptitude Analogy Test**

For the ten participants that completed the test, results indicate a mean of 12.3 points and a median of 12.5 points. Figure 17 presents these results. The X-axis represents participants and the Y-axis the scores they obtained.

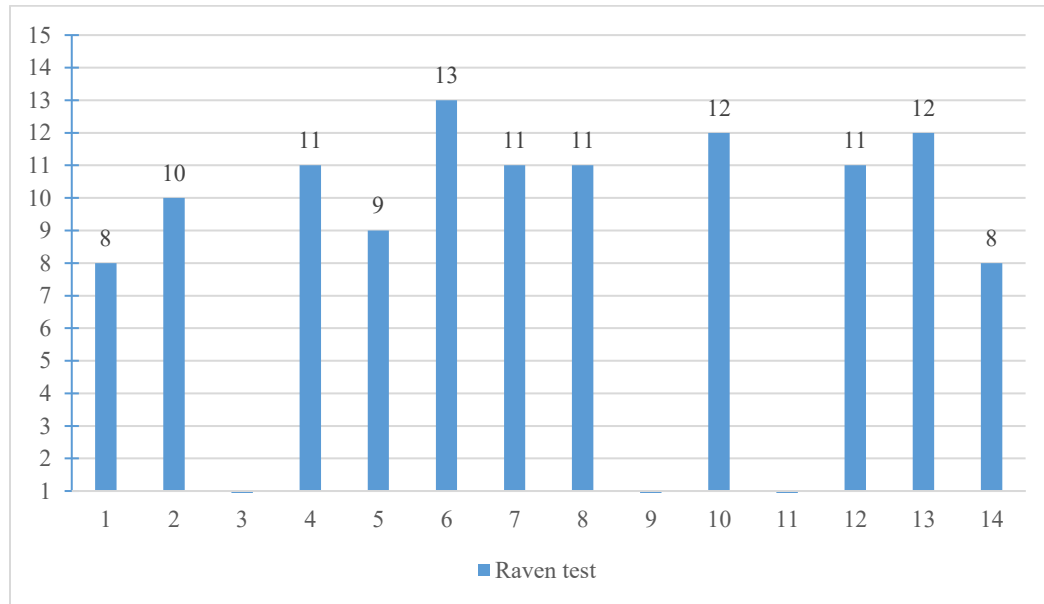


**Figure 17: Results of the semantic analogy test.**

Participants' performed in the middle average, which is commonly expected for 60% of the population. Only two subjects obtained 15 points, a result that only the top 30% of the population reaches and that is equivalent to the performance of experts. Also, one participant scored 14 points and another two 13. Both scores suggest a level of performance only the top 40% of the population reaches, indicating strong lexical skills. The performance of the other five participants placed them in the middle of the evaluation scale. These outcomes suggest that participants' performance ranged from normal to expert, and none reached a high expert or genius level. Conversely, none scored at the bottom, expected of 60% of the population.

#### 4.2.2 Results of the Raven Test

For the 11 participants that completed the test, results show a mean of 10.5 points, a median of 11 points. The results of the Raven test are presented in Figure 18, in which the X-axis represents participants and the Y-axis the grading scale.

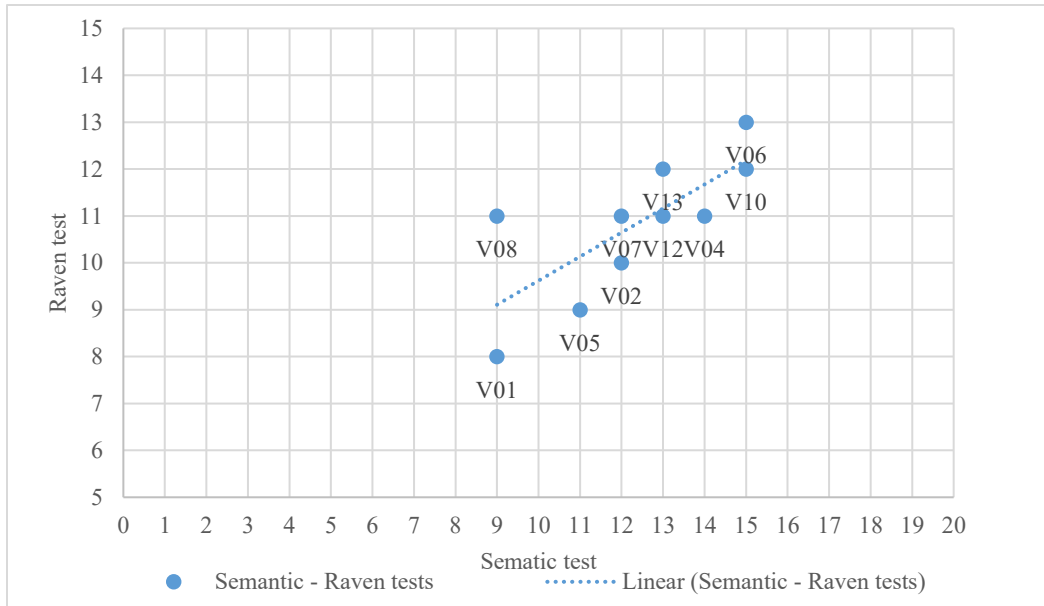


**Figure 18: Results of the Raven test.**

With a mean of 10.5 and a median of 11, participants' performance placed them in the top 30% of the population, which is equivalent to experts' performance. Two participants scored 12 points and one 13 points, reaching the level of high experts in visual cognition. In addition, two subjects correctly answered eight problems, which ranked them in the top 40% of the population, considered high average performance in visual cognition. These outcomes suggest that the participants' performance ranked them as normal to expert subjects; none of the participants, however, ranked on the genius level or the borderline bottom average.

#### 4.2.3 Summary of Psychometric test Results

Participants performed on both tests as expected. Overall, they performed in the middle average on the semantic analogy test (top 60%) but in the experts' level on the Raven test (top 30%). The correlation calculation for both tests was  $r = 0.72$ , indicating a strong relationship between the scores that participants obtained on each test. Figure 19 presents a scatter plot depicting participants' performance on both tests.



**Figure 19: Scatter plot depicting the results of both psychometric tests.**

If architects are considered experts in visual cognition, these results are not unexpected nor surprising. However, rather than taking these results for granted, we should clarify that without testing subjects at the beginning of their formal training after they finish their degrees, one cannot assume that architectural education improves either visual or spatial cognition. Hence, architectural training cannot explain these results.

Lastly, the results of both psychometric tests were compared with the results of the two judges' evaluations of the design processes. The next subsection, prior to extending several ideas encompassing all of the finding, presents the results of the evaluations completed by the judges.

### **4.3 Evaluation of the Design Processes**

Each judge produced a rich set of data evaluating all the design processes. An analysis of their datasets consisted of three steps. First, mean calculations that included all of the dimensional scores evaluated by the judges were obtained. The goal of this step was to provide a general sense of the participants' performance. Then the strength of the relationship between the judges' evaluations was calculated as a measure of reliability. Third, the six dimensions declared in the evaluation rubric were grouped according to the two main categories—originality and quality— that this research assume are predictors of designers' performance.

#### **4.3.1 Results of the Design Evaluation Process**

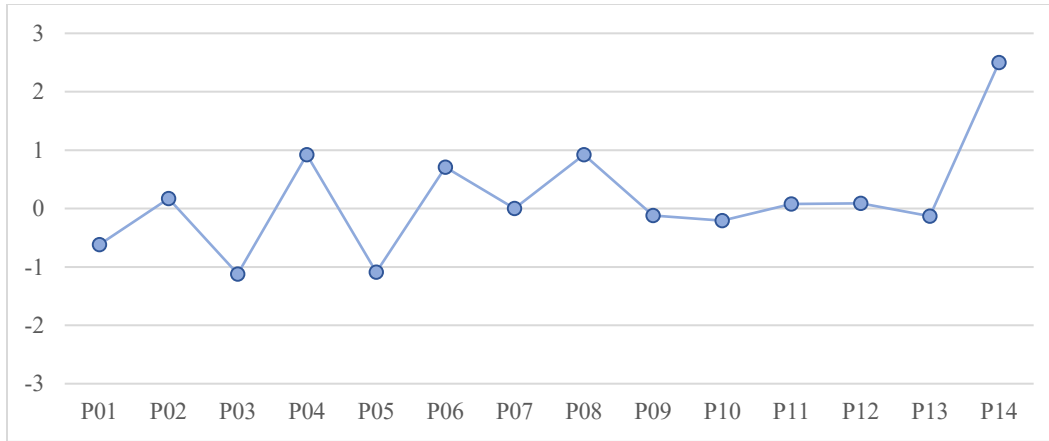
The analysis of the design evaluation process showed that judge 01 assigned higher scores than judge 02. Whereas the mean of all participants' evaluations completed by judge 01 was 3.04 (range = 2.12), the same calculation for judge 02 was 2.89 (range = 3.67). Table 6 presents the scores assigned by each judge to each participant, their average scores, and differences among them, and Figure 20 exhibits the difference between the judges' appreciation of the participants' design processes, reflected by their scores.



**Table 6: Participants' performance according to the scores assigned by the judges.**

Participant	Judge 1	Judge 2	Average	Difference
1	1.71	2.33	2.02	-0.62
2	3.21	3.04	3.13	0.17
3	2.46	3.58	3.02	-1.12
4	3.38	2.46	2.92	0.92
5	3.83	4.92	4.38	-1.09
6	3.25	2.54	2.90	0.71
7	3.46	3.46	3.46	0
8	2.21	1.29	1.75	0.92
9	2.96	3.08	3.02	-0.12
10	3.75	3.96	3.85	-0.21
11	2.29	2.21	2.25	0.08
12	2.75	2.63	2.67	0.12
13	3.54	3.67	3.60	-0.13
14	3.75	1.25	2.50	2.5

Participant number 5 received the highest score while numbers 1 and 8 obtained the lowest scores. The correlation value  $r = 0.448$ , indicates a mild agreement between judges. The low correlation value can be explained by one discrepant score (for participant 14). For all others, the differences among the scores average about 1 point, and if the score of participant 14 is removed, the judges' correlation value is  $r = 0.76$ , well within the accepted value for inter-rater reliability.



**Figure 20: Differences between the scores that judges assigned to participants.**

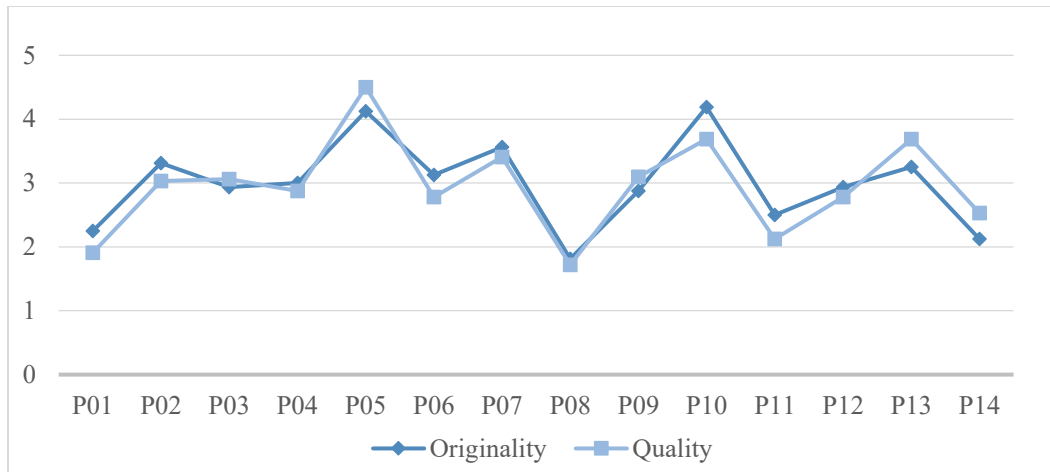
Individual scores assigned to each design task with regard to the dimensions of “creativity” and “novelty” were used to calculate a single value referred to as the measurement of originality (O). Along the same vein, the average value calculated for aesthetic appeal, complexity, overall organization, and richness, or multi-valence, was denoted as a measure of quality (Q) (Prats, Lim et al.). Table 7 shows such average scores for originality and quality by each task brief (t1, t2, t3, and t4), and in correspondence to each participant. Design tasks in this table match the order in which participants performed each task and do not consider the task brief.

It is important to note that the results for originality and quality dimensions do not exhibit significant variation if viewed across participants’ tasks. Indeed, the standard deviation of originality for all four design tasks was  $\sigma = 0.78$ , and the standard deviation of quality for the design tasks was  $\sigma = 0.83$ . The correlation between the average scores for originality and quality that the judges assigned to each participant was as high as  $r = 0.90$ .

**Table 7: Scores for originality and quality assigned to each participant.**

	O t1	Q t1	O t2	Q t2	O t3	Q t3	O t4	Q t4
P01	2.25	1.63	2.75	2.75	1.50	1.63	2.50	1.63
P02	3.25	2.75	3.50	3.25	3.25	3.25	3.25	2.88
P03	3.00	2.75	2.50	3.13	3.25	2.88	3.00	3.50
P04	3.00	2.75	3.00	2.75	3.25	3.00	2.75	3.00
P05	4.00	4.25	4.50	4.50	4.00	4.63	4.00	4.63
P06	3.00	2.88	3.00	2.50	2.75	2.38	3.75	3.38
P07	4.25	3.38	4.00	4.25	3.75	3.38	2.25	2.63
P08	2.50	2.13	1.50	1.63	1.50	1.25	1.75	1.88
P09	2.50	3.00	3.25	3.75	2.50	2.38	3.25	3.25
P10	3.75	2.63	4.50	4.38	4.00	3.75	4.50	4.00
P11	2.00	1.63	2.00	2.00	3.25	2.75	2.75	2.13
P12	2.75	2.75	2.50	2.13	2.50	2.75	4.00	3.50
P13	3.25	4.00	3.25	3.50	3.25	3.75	3.25	3.50
P14	2.00	3.00	2.00	2.50	2.50	2.75	2.00	1.88

However, the analysis also exposes differences in the performance of participants in the eyes of the judges regarding originality and quality. For instance, participants 01, 02, 04, 06, 07, 08, 10, 11, and 12 obtained higher scores in originality while numbers 3, 5, 9, 13, and 14 scored higher on quality. Figure 21 depicts this situation, showing a chart with average scores obtained for the originality and quality dimensions. These values were calculated from the scores that the judges assigned to all of the design tasks performance by the participants.



**Figure 21: Average scores assigned to participants for originality and quality dimensions.**

#### 4.4 Discussion

Several issues emerged from the analysis of the information provided by the questionnaire, the psychometric tests, and the judges' evaluations of the participants' design processes. First, participants that took part in the study, a representative sample of Georgia Tech MArch students with a mean of six years of experience practicing architectural design, felt confident using sketches as a tool for designing. The questionnaire administered at the beginning of session A exposed participants' beliefs that sketches not only support the design process as the core medium but also act as a reasoning device. Also, participants also suggested that sketches move the design forward by fostering design ideas while supporting visualization and communication processes. Second, the results of the psychometric tests indicated that participants scored in the top 30% of the population for visual and spatial intelligence and performed at the middle average level for verbal aptitude. Even though the claim that architects' education explains participants' performance for spatial and visual tests is not valid, claiming that

participants in this particular group performed as expected is. Third, participants that performed well on both psychometric tests did not necessarily obtain the highest scores on design processes. Participant 05 represented the clearest example of this dichotomy. While she obtained the second lowest score on both psychometric tests, the originality and quality of her work exceeded those of the others in the eyes of the judges, who assigned her the highest scores on both dimensions. The judges, however, evaluated the design process of participant 08 as poor even though that participant obtained the third highest score on the Raven test. Thus, assuming that strong performance on psychometric tests does not relate to strong performance in design, the variable “years of experience practicing architecture” was discarded after running a correlation test among these variables. Participants 03, 09, and 11, who did not return, and participant 14, who did not take the Verbal aptitude test, were not counted in the correlation calculation. Table 8 lists the correlation values of both psychometric tests taken by the participants, scores the judges assigned to originality and quality dimensions, and years of experience.

**Table 8: Correlations for years of experience, psychometric tests, and creativity.**

	Years of Experience	Analogy Test A	Raven Test	Originality	Quality
Years of experience	1				
Analogy Test A	0.093	1			
Raven Test	0.078	0.752	1		
Originality	0.065	0.581	0.172	1	
Quality	0.198	0.438	0.114	0.933	1

Strikingly, none of these four factors show a significant correlation value with the variable “years of experience practicing architecture,” as might be expected since participants’ experience ranged from one to eleven years. Thus, the most plausible hypothesis to explain such result is that individual differences regarding participants’ performance could prevail over their design experience.

In sum, this chapter presented outcomes obtained by an analysis of the three sets of data, mostly in descriptive terms, in several ways. First, it disclosed the results of the questionnaire that participants responded to at the beginning of session A. The results showed that while all participants used sketches in their design projects, they also attributed design ideas to sketches. Participants also assigned a key role to sketches and ideas as responsible for moving design processes forward. As mentioned early in the chapter, the design cognition literature has provided extensive evidence of this process (Goldschmidt, 1991; Suwa & Tversky, 1996, 1997; Purcell & Gero, 1998; Smither, 2001; Menezes & Lawson, 2006). The intention here, instead of corroborating knowledge provided by the community in the field of design cognition, was to clarify if participants could carry out the design process using sketches as the only medium of work. It is also worth mentioning that it was not expected that participants envisioned the role of sketches as reasoning devices. Lastly, participants assigned a major role to both ideas and sketches as responsible for advancing the design process.

After presenting the questionnaire results, the chapter presented the results of both psychometric tests. Participants performed as expected, demonstrating average performance on the Analogy Test A and expert performance on the

Raven test. However, as mentioned, results of the overall analysis did not explain their performance. Thus, the idea that formal design training might be associated with cognitive performance remains untested.

The third group of outcomes presented in this chapter were the design evaluations. As mentioned, two judges evaluated the 56-design process using six dimensions that we later reduced to one metric for originality and another for quality. Design evaluations pertained to design processes, not design outcomes. We used these scores to run correlation tests against the outcomes of both psychometric tests as well as the years of experience participants declared in the questionnaire. Results of the correlation tests exposed a weak relationship between the evaluations of the judges and the scores of the participants on both psychometric tests, and no relationship between evaluations and years of experience. This finding was striking and unexpected. Since participants significantly differed with regard to their years of experience in architectural design, we expected to see the impact of experience on the design evaluations. Seeking an explanation for this inconsistency, the next chapter presents findings that emerge from the study of the participant's design processes.

## **CHAPTER 5 DESIGN DIAGRAMS AND DESIGN**

### **EPISODES**

As stated in the research problem and the framework of the investigation, an observational study of design processes arose as the most suitable approach to the investigation of plausible answers for the research questions. Thus, to present the findings from such design processes, the data analysis consisted of reviewing two sets of information: the diagrams participants made and the design episodes (DEs), which emerged from the first cycle of protocol analyses, they undertook. Framing the analysis in such a particular way involved two expectations. First, the solution of unknown design problems should have demanded more diagrams than the solution of known design problems. Second, unknown design problems should have demanded more DEs than familiar design problems. These assumptions stand on the work of Goldschmidt and that of Schön and Goel, discussed in Chapter 2.

Thus, the assumption was that participants should have drawn more diagrams and developed more DEs for the Teahouse exercise. It is important to remind readers that, because the participants were unfamiliar with a teahouse, its design was more challenging than that of the facility for events and parties. After all, it is highly unlikely that participants knew the design of Japanese teahouses in which the tea ceremony is performed in a traditional ceremonial way. The other assumption was that participants had considerable knowledge about facilities for events and parties.



This approach demanded the review of all the diagrams that the participants had generated for the 56 design processes recorded on video. The author carefully reviewed both sets of information and then identified and coded each unit of analysis. The results of the analysis account for various kinds of diagrams, episodes, and times that participants spent on them, all of which determine the content and organization of this chapter.

This chapter has three major sections. The first part presents results of the analysis of the diagrams generated by the participants. The analysis specifically sought patterns in their diagrams by identifying the quantity and the type of diagrams as well as the use of various types diagrams, which could have emerged systematically after filtering the data by both task order and task brief. The analysis also considered the time participants spent producing the diagrams, classifying such timeframes as “drafting episodes.” The second part of the chapter provides two sub-sections that summarize, in descriptive terms, the outcomes of the first cycle of the protocol analysis. This analysis was carried out in light of the effect that task order and task brief might have had on the design processes. The chapter ends with a discussion of the various findings and issues that emerged from reviewing the two datasets.

### **5.1 Report of Diagrams Made by Participants**

The analysis of diagrams relies on an understanding of the cognitive artifacts that help architects represent their designs and trigger and facilitate design reasoning.

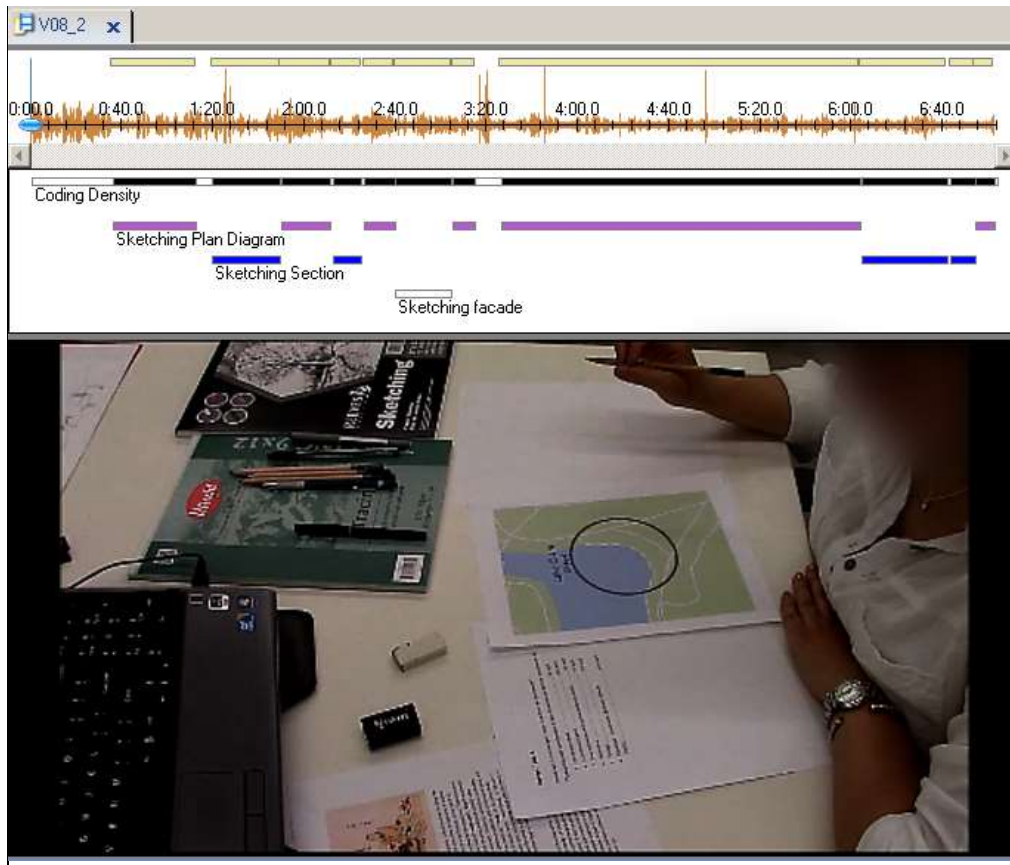
Briefly, the coding scheme presents six categories, and before presenting the results three matters worth mentioning. First, the categorization includes the time participants spend formulating and solving design issues while creating diagrams that capture such issues, which includes but is not limited to the time they spent drawing such diagrams on paper. Therefore, drafting episodes detected after coding the records include the participants' gesturing time and drafting pauses, or time in which they were not sketching. This clarification is worthy of mention for two reasons. First, designers' engagement with diagrams and sketches while designing has been widely reported (Gabriela Goldschmidt, 1991; Menezes & Lawson, 2006; Purcell & Gero, 1998; Schön, 1987; Suwa & Tversky, 1997) and recognized as a particular type of reasoning that pertains to design as a *way of knowing* (Cross, 1982).

Another reason is that gesturing is known to convey spatial and temporal information that might not be present in verbal utterances of participants (Yagmur-Kilimci, 2010) and that it supports a number of functions that relate to both the design process and designer collaboration (Visser, 2009). Hence, this study must be explicit when it identifies patterns in the diagrams of participants as they construct representations in their design tasks. Although the results of the first cycle of coding exposed episodes of high-level cognitive processes, they did not capture specific mental content regarding participants stock of knowledge.

The number of episodes detected, time spent by participants drawing, and the number of diagrams do not correlate with each other. Somehow this constitutes evidence for the claim that formulating designs is hardly a straightforward process. One must be reminded that episodes are units that denote

time spent by participants dealing with specific matters. Diagrams, however, relate to the need to build problem representations. Thus, more sketches and diagrams indicate that a problem formulation was more complicated or denote more refinement in the design outcome. Indeed, observations of the recordings reveal that while some participants continued working on the same diagram until the end of the task, others drew and revisited several of their diagrams to address diverse design issues. Figure 22 exemplifies this situation. In the figure, each colored stripe represents the time it took to draw a particular kind of diagram, and each stripe chunk depicts an episode in which the participant was solving a design issue with a specific diagram. Thus, the purple stripes show six episodes in which the participant engaged in sketching diagrams of the floor plan despite drafting only two floor-plans. The blue stripes represent the four episodes in which she engaged in drafting section diagrams, despite creating only three sections for this particular design task. In the same vein, the single white stripe represents an

instance in which she drafted a façade for this task.



**Figure 22: Example of coded drafting episodes**

Overall, the author wishes to clarify that the time that participants engaged in solving design issues while representing them in various diagrams drove both the segmenting and coding processes. Particularly, movements and switches among diagrams, for instance, each time participants started a new diagram or moved back to another diagram, was what drove the segmentation of the records.

After the protocols were coded, several general results that emerged showed that while participants produced 195 diagrams in total, they went through

381 drafting episodes, during which time they engaged, created, and manipulated such external representations. A summary of the results appears in Table 9.

**Table 9: Number of diagrams and drafting episodes.**

	Floor Plans	Sections	Façades	Views	Bubble Diagrams	Total
Drafting	105	43	9	23	15	195
Episodes	203	65	5	26	10	381

The summary indicates that when formulating design ideas, participants used floor plans as the most important resource in their toolkit and that section diagrams were the second most frequently used tool. On the other hand, they scarcely made use of facades, perspective views, or bubble diagrams to address the formulation of design problems. Labeling was discarded because most participants did not use labels, and only three of them hardly wrote down labels in one or two diagrams. Overall, this outcome corroborates the popular belief that architects rely mostly on the construction of floor plan schemes to address their designs and that they regularly accompany the use of such type of representations with the use of section diagrams.

Below, Sub-section 5.1.1 presents a discussion of the count of diagrams. In light of the effect that task order and task brief might have had on participants' performance, sub-section 5.1.2 discuss results attained from coding drafting episodes.

#### 5.1.1 Diagrams report

As mentioned, participants made 195 diagrams, including floor plans, sections, facades, views, and bubble diagrams. Apparently, they drew their

diagrams in completely random fashion, which does not relate to task order or task brief. Table 10 summarizes the diagrams that participants generated on each task.

**Table 10: Number of sketches produced by each participant on each design task.**

T 1	4	3	3	3	6	5	3	7	6	3	2	7	4	2	58
T 2	2	5	5	4	7	2	2	6	7	2	5	3	3	3	56
T 3	1	3	1	3	3	7	1	5	4	3	2	4	3	2	42
T 4	2	4	3	2	3	4	2	3	5	2	2	2	3	2	39
TU	4	5	3	3	6	7	2	3	7	2	2	2	3	2	51
TP	2	4	5	3	3	5	1	6	4	3	5	7	3	3	54
EP	2	3	1	2	7	4	3	5	6	2	2	4	3	2	46
EU	1	3	3	4	3	2	2	7	5	3	2	3	4	2	44
	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	Σ

The upper section of Table 10, consisting of rows T1, T2, T3, and T4, lists the number of sketches produced by participants according to the order in which they faced task briefs. T1, T2, T3, and T4 stand for the first task solved, the second task solved, and so on. The bottom part of the table clusters rows TU, TP, EP, and EU, and shows the number of sketches participants produced for each brief. TU stands for the design of the teahouse in the urban setting, TP for the teahouse in the natural setting, EP for the event facility in the natural setting, and EU for the event facility in the urban site. The column at the far right of the table shows the total number of sketches produced on each occasion. A cell color accompanies a cell value and graphically represents the number of sketches participants produced. Dark red represents one sketch and dark green represents seven sketches, the maximum number of sketches a participant generated for a

single task. White, light green, and light red indicate that participants made two, three, four, or five diagrams during the tasks. It is important to remind that tasks were assigned in random fashion and participants did not have the opportunity to choose which one solve first and which one at last.

Table 10 yields three observations. The first is large variability in the number of diagrams participants produced for each task.

The second observation regards the total number of sketches (right column) for task order and task brief. The summary reveals that participants produced more sketches on the first and second tasks, and for the teahouse than for the events and parties' facility. Indeed, the table shows a reduction in the number of diagrams by the order of the tasks. Likewise, the table suggests that participants had more problems with the teahouse representations than with the event facility representations, although no discernible pattern occurs in the number of diagrams used for each brief. In other words, the number of diagrams produced for the event facility was slightly lower than that for the teahouse.

A plausible explanation for such a result is the high variability among the participants. Such variability might be rooted in the specific adjustments that participants most likely made when addressing design issues pertaining to each task. Indeed, as the research design and coding scheme stated, each task demanded the formulation of a discrete number of design issues, and participants had to address all of them. To address such design issues on each task, participants chose to draw from their various procedural resources available in their stock of knowledge.

The report of sketches summarized in Table 10 does not constitute evidence that participants' lack of familiarity with the teahouse problem accounted for their need to render more representations of the formulation of the design problem. However, the mild increase in the number of sketches that the teahouse problem demanded suggests that a relationship between problem representation and problem solving does exist.

In short, while fatigue and even boredom might be suitable explanations for the decrease in the number of diagrammatic representations from task one to task four, these results partially suggest that familiarity with the task itself might have played a role in the number of representations that participants produced to formulate their designs ideas.

The third observation from the results shown in Table 10 corroborates that drafting design diagrams is not a straightforward process. The relevance of this observation is that while indeed the number of diagrams participants generated could have been the results of their familiarity with the particular design problems, lack of straightforwardness suggests difficulty embracing the matter for which these diagrammatic representations were being drafted. At a cognitive level, difficulty embracing such design matters may have been a more complex phenomenon than the issue of unfamiliarity with the task, which may then have demanded that the participants generate more representations to formulate the problem. Both a lack of familiarity and the demand for novel representations might have accounted for such a struggle. Evident in the summary presented in Table 10, this explanation might provide the catalyst to proposing a new hypothesis regarding the condition under which the participants formulated their



design problems. However, before this study states the implications of these results for the formulation of design problems, completing this overview necessitates a revision of the results regarding the drafting episodes.

### 5.1.2 Drafting episodes

As mentioned earlier, the goal of the coding process was to identify episodes according to the types of diagrams participants produced. Table 11 presents the descriptive statistic calculations of the number of drafting episodes detected in each drafting category.

**Table 11: Summary of descriptive statistics for drafting episodes.**

	Plan	Section	Views	Bubble Diagrams	Façade
Number of tasks	56	56	56	56	56
Number of episodes	203	65	26	10	5
Mean	3.63	1.16	0.46	0.18	0.09
Range	10	5	4	2	1
Minimum	1	0	0	0	0
Maximum	11	5	4	2	1

The results presented in Table 11 suggest that participants engaged in drafting floor-plan representations at least three times as often as they did in sketching any other type of diagram. Overall, these results indicate that participants used floor-plan diagrams to address design issues and sporadically diverted their attention to drafting or interacting with other types of diagrams. The number of episodes in which participants engaged in producing floor-plan diagrams is consistent with the results shown in Table 9, which lists the number of such diagrams. Thus, although participants drew at least three times as many

floor plans as they did any other type of diagrams, they engaged in design issues three times as much as they did in floor plan diagrams. Thus, both the number of diagrams and the number of episodes coded suggest that (most) participants formulated their designs using floor-plan diagrams. Indeed, with a few exceptions, participants always began their design processes by drafting floor plans, and all of them used floor-plan representations at some point while formulating their designs.

Table 12 complements these findings and presents the percentage of time participants spent out of the overall time they spent drafting each kind of diagram.

**Table 12: Average of time participants spent drafting each type of diagram.**

	Plan	Section	Views	Bubble Diagrams	Labeling	Façade
Mean	53.17%	11.96%	7.14%	3.17%	3.92%	0.93%
Minimum	20.04%	0.00%	0.00%	0.00%	0.00%	0.00%
Maximum	95.47%	46.88%	56.17%	41.03%	41.89%	20.99%

On average, participants spent half of their time drafting floor-plan representations. Indeed, they used at least 20% of their time drafting such diagrams, and the 56 design processes exhibit this type of diagramming. In short, participants tended to formulate design proposals and design issues with this type of representation.

Together, these results provide evidence that participants used at least half of their allotted time, produced three times as many floor-plan diagrams, and addressed most of the design issues while engaging in drafting these diagrams. Also, results of the correlation test suggest that more is going on beyond the number of representations, the number of episodes, and the time participants spent

drafting diagrammatic representations while formulating their architectural designs. With the intention to clarify such “fuzziness,” the next section presents results obtained after the first cycle of coding the protocols of the DEs.

## 5.2 Report of Design Episodes

As units of analysis, DEs allow the advancement of design processes by gathering cognitive processing and drafting actions. DEs also capture the time frames in which such processing and actions occur. This research examines three categories for DEs that participants deal with: site matters, programmatic concerns, and formulation of the building image and character. To perform this report, DEs emerged from segmenting the data following Chi's functional steps for coding protocols. The content mentioned by participants when they are thinking aloud served as the primary driver to segmenting the data. Overall, 736 DEs emerged as results of the protocol analysis after coding the 56 video records, and 248 were tagged as site episodes (SE), 209 as programmatic episodes (PE), and 279 as design goal formulation episodes (BICE). Table 14 presents a summary of descriptive statistics calculated for each type of DE.

**Table 13: Summary of descriptive statistics after the 56 design tasks were coded.**

	SE	PE	BICE
Count	56	56	56
Sum	248	209	279
Mean	4.43	3.73	4.98
Median	4	3	5
Mode	4	3	3
Range	10	10	13
Minimum	0	0	0
Maximum	10	10	13

Results in Table 14 indicate a moderated presence of each type of episode about four times per task. The table also shows that while SE and PE do not present a large variance across design exercises, BICE does. These results can be explained because on a single occasion, a participant did not address site issues, and in another, a participant neither recalled nor handled programmatic matters. In six out of the 56 design exercises, participants did not explicitly formulate an image for their teahouses. Coded episodes also allowed the calculation of descriptive statistics regarding the time participants engaged in each episode. Table 15 presents these results. Overall, these results indicate that, on average, episodes tend to emerge four times per design process, with a few exceptions in which participants produced many episodes.

**Table 14: Percentage of time spent on each episode.**

	<i>t</i> Site	<i>t</i> Program	<i>t</i> Bice
Count	56	56	56
Mean	30.63	28.36	39.97
Median	28.95	23.91	43.31
Mode	14.12	-	0.00
Maximum	81.21	86.21%	97.54%
Standard Deviation	16.30	19.76	25.26

Results also show that the BICE emerges in different ways and with more outliers than SE and PE, which are clustered around their means, suggesting that participants' behavior is more predictable when solving design issues related to SE and PE than it is when solving issues related to BICE.

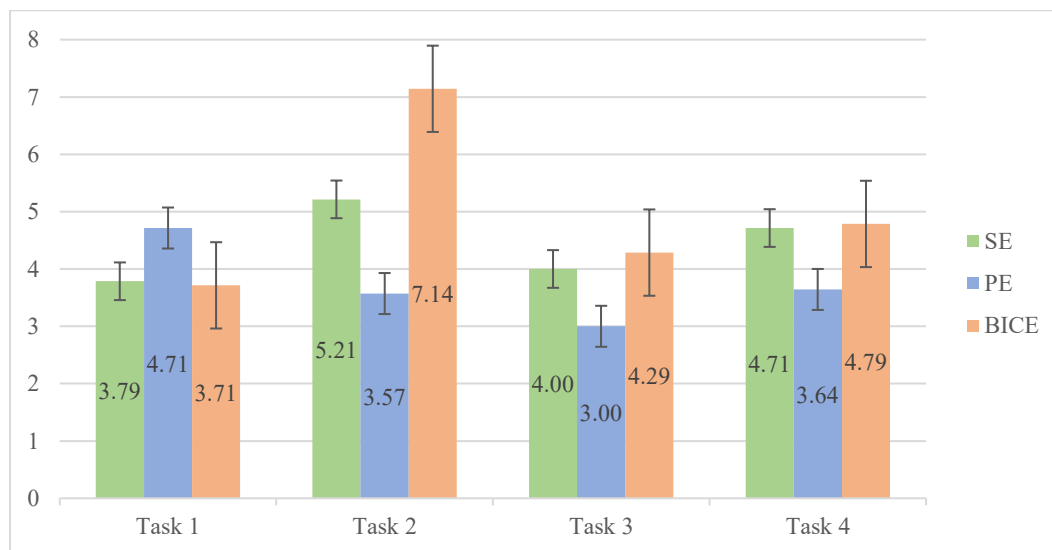
The next subsection presents a summary of results of calculations found after analyzing the data in two ways: episode emergence regarding the task order and the task brief. The assumption behind looking at the data in these two ways is

that both task order and task briefs might have played a role in how many episodes emerged as well as how long the detected episodes were. Thus, while some architects went through more episodes in the first or second task, others

Also worth noting that participants might have developed more or less SE, PE, or BICE according to their familiarity with the sites, the program, or the design change. The two accounts presented below clarify these issues.

### 5.2.1 Report of the design episodes by task order

About the number of sites and programmatic episodes, results suggest that DEs emerged independently of the task order. The average time participants engaged in each type of episode was also consistent with one exception—the average time they spent solving programmatic issues on task 1. Figure 23, below, presents the average number of episodes by the order in which participants performed the tasks.



**Figure 23: Mean values for the number of episodes by the task order.**

The fact that seven out the four teen participants used more than 50% of the time allotted on site episodes explains the average time spent on programmatic matters during the first task. The average values for the design goal formulation episodes show a different behavior. That is, the mean of BICE that emerged during the second task ( $X=7.14$ ) was almost double that of BICE that was observed in tasks one, three, and four. Table 15 presents, by task order, the average increments in the percentage of time used by participants to elaborate BICE.

**Table 15: Time spent by participants on BICE from tasks 1 to 4.**

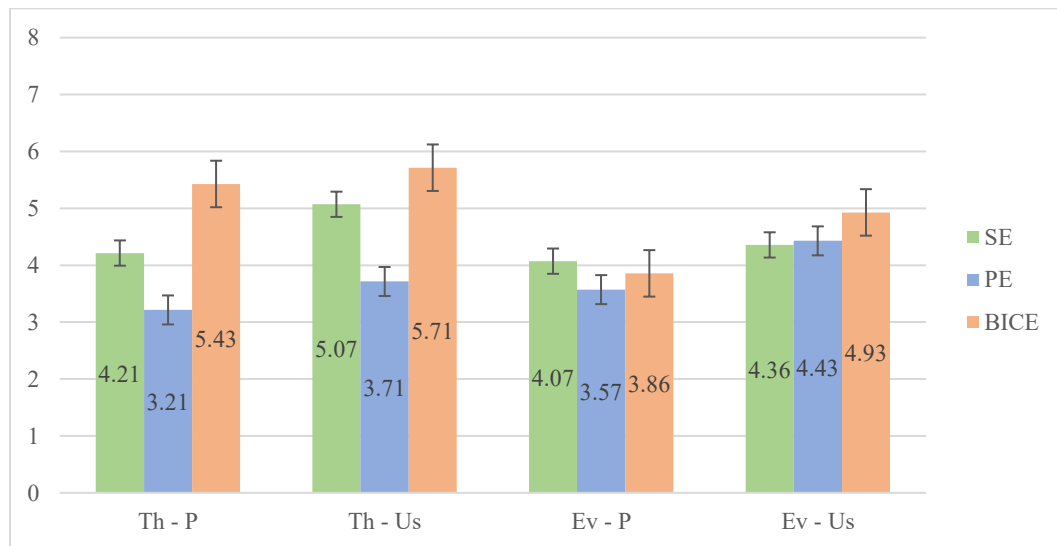
	BICE T1	BICE T2	BICE T3	BICE T4
P01	8.32%	0.00%	0.00%	0.00%
P02	33.70%	18.51%	46.47%	34.39%
P03	35.97%	57.14%	41.57%	50.56%
P04	0.00%	0.00%	58.88%	61.72%
P05	23.57%	71.63%	46.24%	78.07%
P06	38.90%	43.42%	27.90%	50.63%
P07	64.53%	61.87%	88.15%	55.04%
P08	0.00%	60.96%	21.24%	25.06%
P09	32.60%	59.43%	48.48%	22.83%
P10	46.77%	55.56%	61.61%	97.54%
P11	10.66%	32.05%	72.23%	64.79%
P12	48.31%	40.12%	25.07%	88.34%
P13	37.66%	36.22%	50.98%	48.89%
P14	15.51%	53.42%	36.37%	43.19%
$\Sigma$	28.32%	42.17%	44.66%	51.50%

The effect of cognitive fatigue offers a suitable explanation for the time increment. However, it is essential to clarify that while indeed, some participants might have felt fatigue after the second or third exercise, others might have entered *the zone* (Csikszentmihalyi, 2009) after warming up. Cognitive fatigue, as

an argument, does not explain that while BICE average time increases, SE time decreases, and PE time remains the same after cognitive resources demanded by task 1 decrease substantially. Undoubtedly, several opposing factors are responsible for such a time increment, fatigue and “entering the zone” are among them. Nevertheless, another plausible yet straightforward explanation for the time increment is that the participants may have struggled while formulating design goals but felt more comfortable while handling site and programmatic issues. To elucidate the time issue, the next sub-section, before exploring the validity of this assertion presents results for the number and the length of DE from a dataset ordered by task brief instead of task order.

### 5.2.2 Report of design episodes by task brief

Figure 24 presents the results of the average values of the number and the length of episodes grouped by task brief.



**Figure 24: Mean values of the number of episodes by design brief**

Together, these results suggested two things. First, the participants spent less time formulating design goals when the design brief was familiar, as in the case of the facility for hosting events and parties. Second, participants' might have switched the focus of their attention from formulating design goals to addressing site issues and exploring the possibilities that the site offered, as was the case with the urban setting. Thus, participants might have chosen when to engage in BICE; for instance, if they had felt more familiar with the task, they may have chosen to do so. On the other hand, if they had been less familiar with the design problem, they might have chosen to address site or programmatic issues. Certainly, this idea complements the third plausible explanation of the emergence of BICE in light of task order, suggested previously. Participants struggled at formulating design goals for unfamiliar tasks, and instead, preferred handling site and programmatic issues when formulating their design proposals during such unknown scenarios.

### **5.3 Interaction of Design Diagrams and Design Episodes**

Looking at the interplay of diagrams and design episodes is one of the key concerns of this study. Indeed, the purpose of the research questions is to clarify the nature of such interplay. However, an apparent lack of patterns emerged in comparisons between participants' use of diagrams and DEs observed.

The use of floor plans remains constant across the three categories of DEs. The uses of section diagrams differ in that participants tend to use them primarily to address goal formulation ideas and then site issues. The use of perspective views tends to be universal in solving programmatic matters such as the use of



bubble diagrams. Thus, supporting the results of Section 5.1.1, the floor plans indeed differ from all of the other kinds of diagrams, and their use is versatile and consistent across all kinds of DEs. It is important to note that participants alternated their attention among design concerns, but such attentional movements did not always entail switching diagrams. Thus, the very notion of design movement shows an underlying and permanent presence that can quickly be taken for granted. Alternating among the types of diagrams and DEs provides evidence for the very notion of design movement, and as such, are aligned with the research questions raised by this study. The issue of design movement will be further explored in Chapter 6. The next section offers a summary of the findings that emerged from analyzing the set of results presented in this chapter.

#### **5.4 Summary**

This chapter presented and discussed findings that emerged from the categorization of the participants' drawings and the segmentation of video recordings into protocols that were classified into drafting and design episodes. The review of the data consisted of the task order and the task brief, which stemmed from the hypothesis that the number of diagrams made by participants would decrease as they approached the final task and that they were more likely to struggle when formulating the teahouse than they would formulate the event facility. Thus, the purpose of the analysis of diagrams was to examine if architects sketch more diagrams when they formulate unknown design problems. The purpose of the analysis of DEs, however, was expected to provide insights into the assumption that unknown design problems require the formulation of more

DEs than familiar ones. Overall, four key findings about design processes emerged from the analyses, all of which shed light on the research questions formulated in this study.

The first key finding is that participants generated a large variation in the number of diagrams they made across tasks. Such randomness indicates that participants used sketches to formulate design problems in a random fashion, and it implies that participants selected units of knowledge at will when they formulated their designs. This outcome is most likely consistent with the notion of flexibility that sketches, as reasoning devices, support and allow.

The second finding revealed that participants produced more sketches for the teahouse than for the events facility, and fewer sketches overall as the tasks progressed. These two outcomes are consistent with the assumptions pertaining to the way in which participants were expected to produce sketches.

The third finding corroborates that participants spent more time drawing floor-plan representations than they did any other kind of diagrams. In addition, it was observed that the manner in which they used floor plans with regard to other types of diagrams differed.

Another key finding that emerged from the comparison of drafting episodes and design processes in light of the three major coding categories —SE, PE, and BICE— was that randomness and high variability seems to drive the way in which participants navigated design processes. Such a review considered the number of episodes in each category and the time spent on it.

The analysis, which served to enhance our understanding of the incidence of task order, shows that participants always navigated more SEs in the first task

and more BICEs in the second. However, the analysis does not answer the question of why BICEs emerged more in the second task. A possible explanation is that participants dedicated their attention to SEs in the first task because dealing with the content of a site may rely on a strategy based on tackling known constraints. Such constraints may be tied to specific procedures that address the four most common problems that the notion of site offers: borders, circulation patterns, natural conditions, and views (Soza, 2011). In addition, as expected, the teahouse task (i.e., the unfamiliar task) demanded more BICEs than the party and event facility.

Participants also developed more SEs for the teahouse task, suggesting that participants may have preferred to address site matters before programmatic matters if the design problem appeared more complex or unfamiliar. A way in which one might find evidence to support such a speculation is to observe how many times participants began facing SE and PE for both the teahouses and the event facility. Indeed, if the participant preferred to address SE rather than PE for unfamiliar problems, this choice may constitute evidence for claiming that architects, when facing unfamiliar design problems, prefer to address site issues in an effort to seek clues that may trigger or help them recall other kinds of representations, which might make sense for their inner narrative. It is also possible to think that, rather than formulating an image of the building for unfamiliar tasks, participants may actually have addressed site and programmatic issues when the design problem was unfamiliar. Another implication of this scenario is that at a cognitive level, the flexibility of the content stored in the participants' stock of knowledge is a crucial property of such knowledge

representations that may favor the transformation of ill-defined design problems into design solutions.

Regarding design movements across episodes, along with an apparent lack of a pattern showing how participants made such movements, outcomes of the analyses suggest that the same units of content that participants considered while formulating their designs may have played different roles. For instance, when addressing the site orientation on a task, a participant might not have accounted for the site orientation on tasks two, three, and four. In addition, other participants might have accounted for the site orientation in task two while others did not. Furthermore, the first participant might have struggled while addressing the site orientation on task one, but later approached task 4 in a very straightforward fashion using site orientation as a resource for achieving a major design goal. Thus, the units of content that participants recalled from their personal stock of knowledge for formulating architectural design were a flexible resource that they could use as either a design constraint or a resource for exploring the formulation of design goals. Likewise, design movements related to the substantial number of design episodes in which participants adjusted, changed, and assigned values to design issues while drafting diagrammatic representations of them.

Overall, these observations indicate that the units of content that participants recalled, selected, and used to make design decisions are key components of DEs. The analysis of DEs also provided evidence that participants recalled a similar set of such units of content. Thus, the next chapter presents results that emerged after performing two new cycles of coding and analyses, with

special focus on understanding the role that units of content detected within SE, PE, and BICE play for architectural formulation.

## **CHAPTER 6 UNFOLDING EPISODES**

As the previous chapter showed, the approach selected to draft plausible answers to the questions raised by this research consisted of reviewing participants' design processes along with their sketches and diagrams. Such observations led to the identification of both drafting and design episodes. This approach, leading to the analyses and their outcomes, corroborates assumptions about task order and task brief. Outcomes indicate high variability regarding the way in which participants use sketches and navigate drafting and design episodes, implying that randomness largely drives design processes. New revisions of the data, however, have suggested that participants recall similar issues during design episodes (DEs). Thus, to face the lack of coherence between randomness and the use of a small set of issues that drive design processes, Chapter 6 presents a complementary set of findings obtained after a review six design processes at a very fine level of granularity. The rationale behind performing two new cycles of analysis is to clarify how architects use their common stock of knowledge when formulating designs. If verified, such a provocative assumption might stand as evidence for the existence of a common stock of knowledge and shed light on the issues raised in this research and the motivation behind it.

Chapter 6 is divided into four sections. The first section presents six design processes selected for the second and third cycles of analyses, which delve more deeply into the accounts of diagrams and DEs presented in Chapter 5.

They present new findings attained after new analyses for both datasets were run. The analyses involve dissecting the diagrams into graphical tokens drafted by participants and the examining subcategories, design issues, and design movements inside the DEs. The analyses are bounded by the identification of a measure for design performance in the architectural formulation. Lastly, the chapter concludes by summarizing the findings and their implications for architectural formulation.

## **6.1 Introduction**

The findings in Chapter 5 revealed a great deal of variation regarding the use of diagrams made by the study participants, who generated fewer and fewer drawings as the tasks progressed, but more for the teahouse. Such a demand for more representations of the teahouse was expected because it represented an unknown condition. After all, as expected, the participants' possessed little knowledge about the traditions related to the performance of the tea ceremony. The outcomes presented in Chapter 5 also demonstrated that, overall, participants spent a majority of their time, 53.17%, sketching floorplans. In other words, participants primarily used floorplan representations to drive their design processes. Such a finding constitutes evidence for the claim that floorplans are used differently from other kinds of architectural representations.

The findings of Chapter 5, however, do not reveal much about the elements that constitute the toolset used by participants to drive their design processes. They also do not reveal a great deal about the existence of drawing patterns regarding the frequency or the sequence in which participants use such elements when producing external architectural representations and that drive the design processes. Hence, in light of such results, little can be said about the role that constituent elements in the graphical toolbox of architects played in the participants' design processes. Consequently, the way in which architectural diagrams help architects in their reasoning process remains unclear, as does the way architects use key units of knowledge to formulate their designs, a question raised since the inception of this study. To clarify these issues, this section introduces six design processes developed by the participants and reveals both the methods they use and the content they produce throughout their design processes. Before these cases are presented, however, two methodological considerations require clarification<sup>5</sup>: the criteria used to select cases and the granularity of the data used to run these analyses.

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<sup>5</sup> For the purpose of clarification, these two cycles of coding were completed by the author alone, so inter-rater reliability was not calculated. However, the author discussed the analysis at length



The cases involved the selection of participants and the selection of design tasks. With regard to the participants, judges' evaluations of participants were used to select three levels of performance, with participant 01 in the bottom level, participant 07 in the upper middle, and participant 05 in the highest level. The teahouse, an unfamiliar task, was the task selected in both settings. As explained in Chapter 3, we assumed that the teahouse demanded more cognitive effort, which required more content elaboration during the DEs. In addition, differences regarding the way in which participants' handled site matters should have emerged from the study of both sets of design processes.

The other issue that requires clarification is the need for finer granularity. Running a very detailed analysis of a participant's object of attention at any time during the DEs demanded copies of transcriptions that were explicitly segmented. Utterances were identified following instructions provided by Chi (1997), discussed in Chapter 3, and the process of segmenting transcriptions relied on identifying the object about which participants produced an utterance. Every time such an object of attention changed, the transcriptions were segmented. In other words, the analysis identified a participant's object of attention during each utterance, phrase, or sentence spoken out loud. The goal was to capture objects of the participant's attention as well as their movements from one object to another.

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with fellow researchers and faculty members and took into account that each step could be easily replicated in the analysis.

The underlying assumption motivating the capturing of the set of units of content generated by participants was that it would reveal a participant's stock of knowledge. It would also enable a comparison of the knowledge representations used across tasks and among participants. Having clarified these two issues, this chapter continues by summarizing and presenting the second and third cycles of the analyses.

### Six Design Processes

The presentation of the summaries, describes their actions during the design of the teahouses in the urban setting, presented first, and in the natural setting, grouped later.

#### *Participant 01 - Teahouse in the Urban Setting*

Participant 01's first cycle of coding revealed five major DEs that she carried out to formulate her design proposal. She began the task by briefly engaging in an SE and then moved to a PE, which ended in a short BICE. Afterwards, she developed another SE and finished the task by revisiting programmatic issues in another PE. During the time allotted, she created four diagrams, all of which were floorplan-type representations and each of which accompanied an episode, although the second and third episodes (PE and BICE) were addressed using the same diagram. She used sketching paper to draw the diagrams, and although she put aside the site plan given to her, she kept in within sight for visual reference.

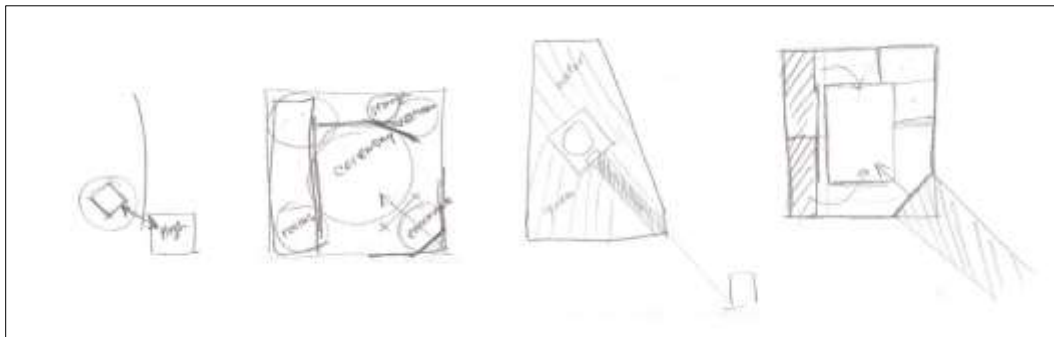
In her first SE, she recalled the condition of the site's western border, facing the High Museum, represented by a square, while drawing a line

representing Arts Center Way and a circle representing the site. Then she mentioned that both the teahouse and the museum were a “kind of artistic program” and a “kind of cultural thing,” so it should be a “kind of dialogue between the two.” While reasoning out loud, she drew an arrow representing the idea of a dialog between the two shapes. Afterward, she said, “So... the positioning of this teahouse should be maybe... something like this, to where... this kind of speaks to that...” while drawing a square representing the main shape of her teahouse inside the circle, previously drawn to represent the site. Thus, as result of her first SE, she fixed the position of her building in the center of the site but also drew a square for the shape of the building. Indeed, even though she moved to the first PE, saying that she did not know “what the shape of the building was going to be yet,” she began her second diagram, saying that she was going to start with a “simple square.” While drawing the new square, she said that the first thing (to think about) was “the entrance” and defined the entrance location with an arrow passing diagonally across the bottom right corner of the square. After defining the position of the entrance with the arrow, she drew various bubbles inside the square representing different rooms, each according to the spaces demanded by the brief. Specifically, she first drew a larger bubble for the ceremonial space in the center of the square and then other bubbles inside and along the perimeter of the square representing dressing rooms, restrooms, and storage. While drawing the major bubble, she mentioned that her “first instinct was to have the ceremonial space kind of in the center, so that you can walk in and that’s kind of the first thing...” and continued, saying that “maybe there’s like some kind of screen here so you have a threshold to then see the ceremony

space.” Thus, by producing these utterances out loud and by drawing a few bubbles and lines inside the square, she defined the layout of her proposal. In short, she drew a bubble in the center for the ceremonial space and then envisioned how someone entering the building should perceive such a sequence of spaces. She recalled a design element, a screen, representing the threshold, and drew a line for it, which, besides carrying such a meaning, was fixed within the layout. Finally, she envisioned the perception that someone passing the threshold would have of such interior space. Then, always inside the square, she drew parallel lines to its edges, representing the inner walls. These traces were tangent to a bubble depicting the ceremonial space, circumscribing it. After labeling a room for each bubble, she moved to the BICE while speaking aloud about envisioning “lots of screens” and picturing how people would perceive them. At the same time, she drafted several lines representing the screens. At this point, she started her third diagram in which she revisited site issues by discussing the border conditions again, and she mentioned and drew a pathway for entering the building and assigned labels indicating a garden and a water feature. She filled both the pathway and the garden area with parallel strokes as hatches, that is, graphic patterns filling each area. Finally, she switched again to her last PE and drafted the final diagram, rendered by a square and straight lines representing exterior and interior walls. She finished the diagram and the episode by drawing four arrows depicting each connectivity option between the rooms inside the layout.

Such was the design process she carried out to formulate a design solution to this task. It is worth mentioning that even after completing the task, the square

she drew in her first episode was, indeed, the shape of the building. Also, she defined the main entrance in front of the High Museum as relevant, but not relevant enough to say that it dominated her design process, by placing the building in the center of the site, the most explicit design decision that she made. The layout of the proposal emerged sequentially inside the limits of the square, rendering the building shape, and pictured design elements and internal views that users should experience in the building. She used a small set of graphical tokens to construct four floorplan diagrams. The set of elements consisted of circles, squares, arrows, lines, hatches, and a few words written down as labels. Overall, the condition faced by the site borders drove her design decisions for both the building position and the entrance location, but the grouping of the rooms and connectivity criteria controlled the development of her layout. Below, Figure 25 shows the diagrams she produced during this task.



**Figure 25: Diagrams drawn by participant 01**

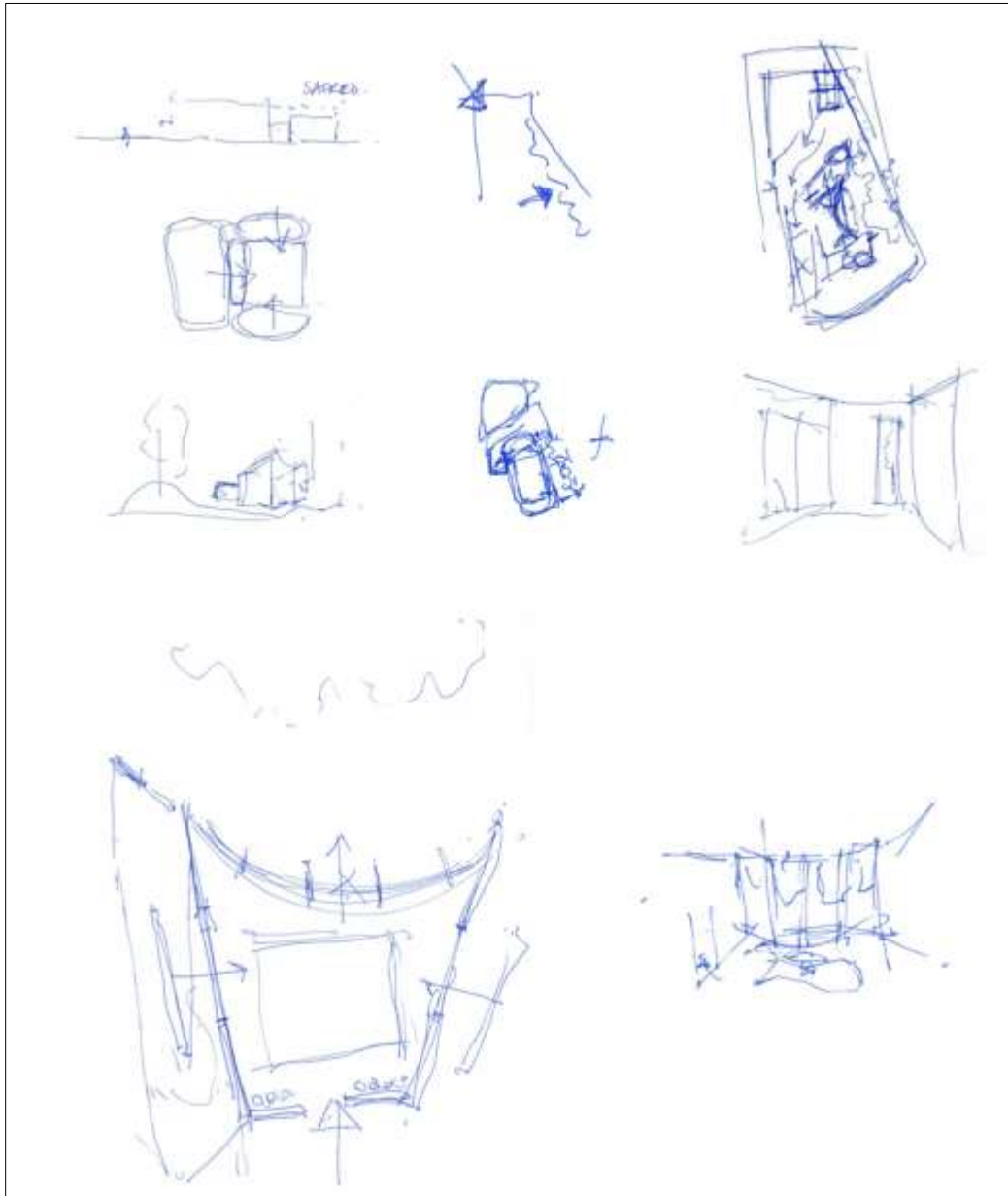
### *Participant 05 - Teahouse in the Urban Setting*

The design process of volunteer 05 addressing the teahouse design in the urban setting was very straightforward. She went through four major DEs: first, a BICE, followed by a PE, then an SE, and finally a very long PE. However, as her

design process unfolded, she interwove the SE and final PE by drawing several diagrams. Altogether, she drew nine diagrams, one for each of the first two episodes, three diagrams in the SE, and four diagrams during the final PE. The diagrams include floorplan representations, sections, a bubble diagram, and interior views of her design.

Volunteer 05 began the BICE by describing an image related to the ceremonial space, specifically to how people would enter it, and at the same time, she drafted a section-type diagram graphically depicting her ideas for such a transition. From there, she moved to a short PE in which she drafted a bubble diagram resembling the sequence of spaces people would go through to enter the ceremonial space. She drew a square bubble for the central space and rectangular bubbles on three of its sides, representing “changing” and “waiting rooms.” In addition to serving as access to the central space, such rectangular rooms help people prepare for the ceremony. Before moving forward, she drew three arrows, each passing through each bubble towards the square, representing the main room. Then she put the diagram aside and started the SE by sketching a section diagram rendering the slope of the terrain and the line of trees on Arts Center Way. She switched to a floorplan diagram by drawing perpendicular lines for the corner of West Peachtree Street and Arts Center Way and stated the “corner condition” as an “urban front” with an arrow pointing towards it. After that, she drew a wavy line resembling the line of trees on Arts Center Way, and another arrow from the center of “the site” pointing towards the trees while enunciating that they would be a “view out of your tea room, that would be the more reflective

space.” Afterward, she began a PE by drafting a floorplan diagram and figuring out the layout of the teahouse.



**Figure 26: Diagrams drawn by participant 05.**

Participant 05 revisited several site issues in the episode even though most of them related to views offered by the site. She took advantage of such views and used them as constraints for driving the formulation of her proposal as well as for reinforcing her design idea. Along the same vein, she addressed all of the grouping and connectivity issues that emerged, giving special consideration to attaching such issues as her main idea (stated in the BICE). She drew three floorplan-type diagrams and two views from the inside of the central space. Overall, it was a very clean and straightforward design process, addressed by several diagrams and fine details, shown in Figure 26.

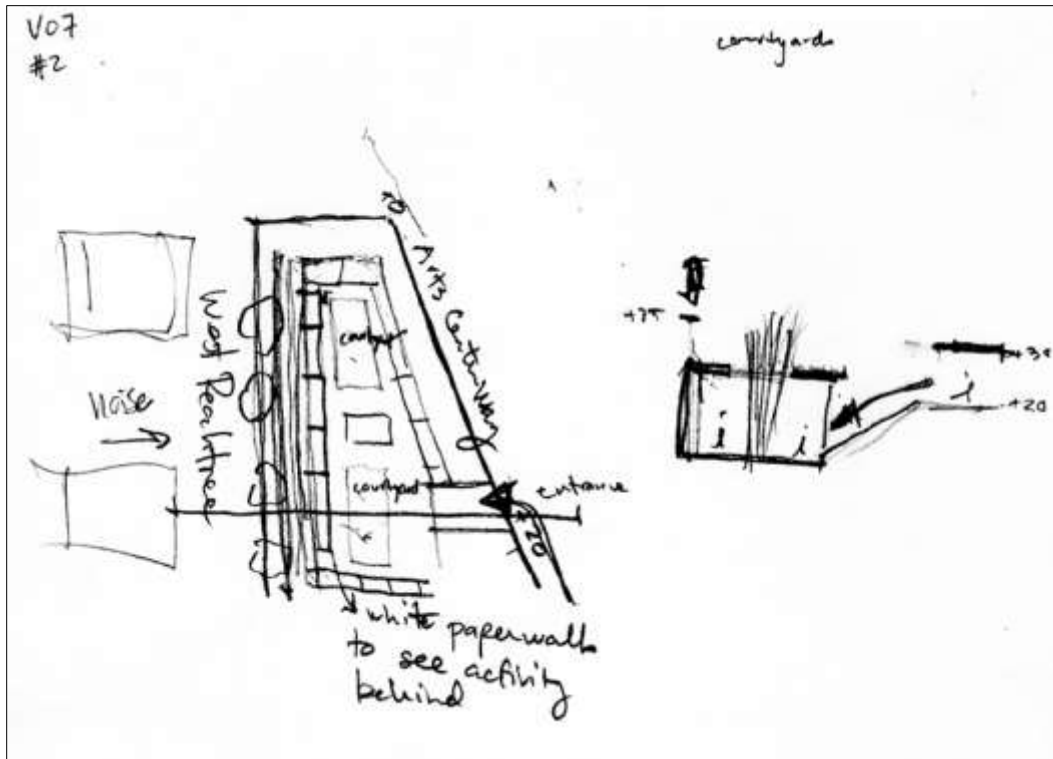
#### *Participant 07 - Teahouse in the Urban Setting*

The teahouse in the urban setting was the second task faced by volunteer seven. The protocol analysis of his design process exposed ten SEs, four PEs, and twelve BICEs. Such an entanglement of episodes was accompanied by the drawing of two diagrams, a floorplan, and a section, shown in Figure 27. Initially, Volunteer 07 fixed his attention on two site issues: the topography, which he declared a “great deal,” and the border condition of West Peachtree Street, regarded as “a very busy street.” While speaking such utterances aloud, he drafted straight lines for each edge of the site until completing the outline of the site. He drew such lines several times and kept mentioning variants of the border conditions, such as the traffic direction on West Peachtree Street, and then Arts Center Way, saying “sloping up” and being a “much quieter street.” These ideas led him to consider placing the main entrance on Arts Center Way. He continued by turning his attention towards programmatic issues, reviewing the brief, and mentioning that



he was envisioning courtyards and corridors “but for the most part kind of inward focused.” Afterward, he went back and fixed the positioning of the main entrance by drawing an arrow near the south corner of the site over Arts Center Way while saying, “...it would be nice if the main entrance were here, on the top.” Then, he turned his attention again, focused on the border of West Peachtree Street, and drew a sequence of circles representing “the street trees,” and several lines parallel to the border representing “several layers” to address the noise issue and the necessity of a “kind of buffer to cut down the noise.” At that moment, 07 kept drafting parallel lines to each border and said, “maybe we could just take... that, this geometry of the site and pull that down...” and returned to the courtyard image by drawing two rectangles within the site representing two courtyards.

Afterward, he changed the focus of his attention again and began sketching a section that he used for defining heights as well as architectural elements and materials. He drew a straight line representing Arts Center Way, an oblique line depicting a ramp for entering into the building, and another straight line for the ground level. He continued drafting lines for a wall over West Peachtree Street for an occupiable roof and several traces of bamboo trees in the courtyards. Then his attention returned to the floorplan diagram. He noticed the “tall buildings” on the other side of West Peachtree Street and returned to the section diagram, where he drew a new portion of the wall on West Peachtree Street to frame a view from the entrance on Arts Center Way towards the skyline of the city.



**Figure 27: Diagrams produced by participant 07**

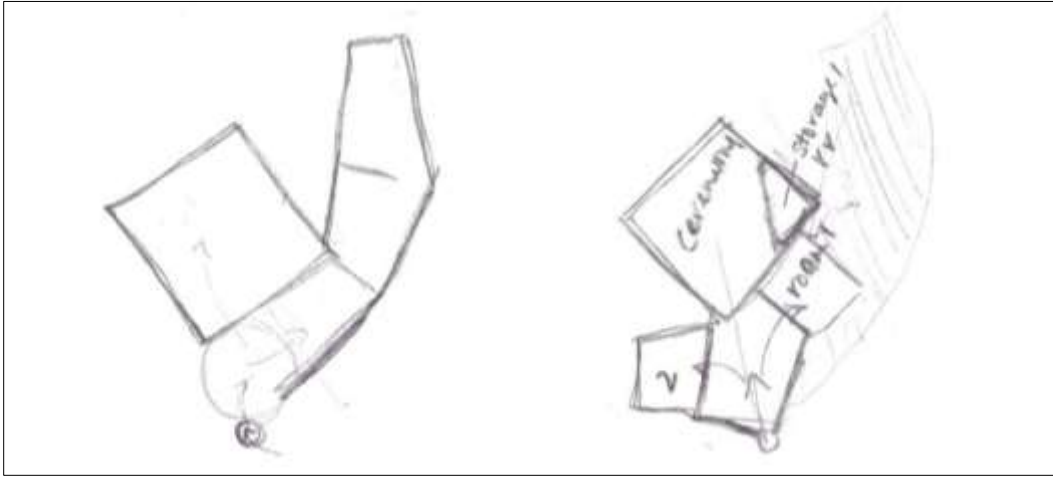
At this point, he returned to the floorplan diagram and drew several small rectangles between the lines representing the wall buffer by West Peachtree Street and rectangles for the courtyards. Such small rectangles represented “a single loaded corridor with rooms on one side.” He finished the task by labeling inner walls as “white paper walls” while saying that such walls were “Japanese architecture walls..., that’s paper”; hence, people would “see their silhouette as walking by, inside the building” and get a sense of all the activity happening within the building.

*Participant 01 - Teahouse in the Natural Setting*

Unlike her previous design process, which was very straightforward, in her fourth design task, presented in Figure 28, volunteer 01 interwove the construction and drew two diagrams (both floorplan-type diagrams) with three design episodes (SE, PE, and SE). She drew her first diagram while navigating the SE, remained working on it even though she moved to the PE, and began her second diagram in the middle of the PE. She continued addressing programmatic matters while drafting the second diagram, and towards the end of the task, she revisited site issues already mentioned. Hence, the third episode was coded as an SE. Unlike in her previous task, she used tracing paper in this task to sketch both diagrams on top of the site plan provided.

The following is a summary of her design process. First, she drew an SE in which she defined the position of the central space on the water by drawing a square shape, which barely touched the edge of the lagoon. Then she drew a PE in which she approached the formulation of the layout by recalling the first site issues, specifically using the pathways in the park for defining the main entrance, a sequence of rooms between the entrance, and the central space. Such an approach did not satisfy her, so she began the second diagram, attempting to fit in all the spaces requested by the brief. Attempting to tackle the layout's formulation, she used squares, arrows, and straight lines as graphic tokens. Grouping rooms and connectivity issues emerged as the leading problems for her formulation. The progressive addition of such graphic elements led to the shape of the building. She ended the task by moving on to the final SE, in which she reconsidered the configuration of the building and the landscape—that they

should “meet” and “engage a little bit better,” showing her implicit recognition that her proposal needed revision.



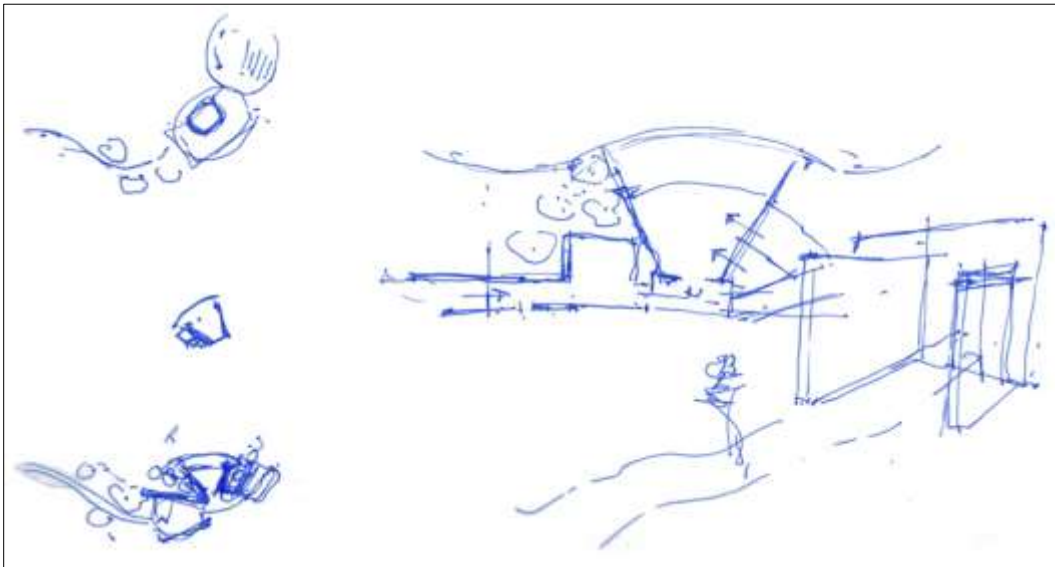
**Figure 28: The two diagrams made by participant 01.**

#### *Participant 05 - Teahouse in the Natural Setting*

The teahouse in the natural setting was the final task that volunteer 05 faced; hence, she already knew the site, the program, and the charge. Her design process exposed five SEs, six PEs, and eight BICEs, all of which combined a variety of design issues, five drafted diagrams in total. Four of the diagrams were a floorplan type, plus an exterior view detailing the entrance of the teahouse. The diagrams drawn by participant 05 are shown in Figure 29.

She started the task by drafting a floorplan diagram and speaking about the border condition of the site, the lagoon, and the existing pathways and using such site issues as constraints to define the layout of her proposal. Then, she began a second floorplan diagram detailing the central ceremonial space while recalling the view towards the skyline of the city. After that, she drew a third floorplan

diagram and completed the layout of the building while mentioning the views towards the outside, defining an entrance, architectural elements, and materials. Then she placed interior walls and mentioned connectivity issues among the rooms and ended the third diagram by adding a balcony to the central space and defining garden areas. At that point, she switched to a new diagram and drafted a diagram rendering the view towards the entrance of the building while recalling the architectural elements and materials that she had previously proposed. She finished the task by drafting a new floorplan diagram, larger than the others, and detailing in with almost all of the elements and features she had already defined.



**Figure 29: Diagrams produced by participant 05.**

Once 05 defined the building location, she recounted aloud the importance of the views several times. The layout definition emerged, relating to the tactic of placing rooms along the edge of the lagoon, which was reinforced by the positioning of the central circulation area behind the rooms. She sketched the main entrance and envisioned the experience of someone entering the building,

seeing a variety of architectural elements as well as materials blocking views of the skyline of the city, walking inside the building towards the ceremonial room, entering it, and discovering the view oriented towards the lagoon and the skyline. She used both the sketch of the outdoor view and the last floorplan diagram to work out such a navigation experience during the refinement of her proposal. She solved the layout flawlessly and detailed several architectural elements. Her utterances suggested an intensive use of imagery regarding user experience navigating the building and viewing the outside scenery.

#### *Participant 07 - Teahouse in the Natural Setting*

The teahouse in the natural setting was the third task volunteer 07 performed. Although he developed a single floorplan diagram during this task, an analysis of his protocol showed three SEs, six PEs, and five BICEs, shown in Figure 30. He started his design process by fixing his attention on the edge of the lake and the nearby pathways and drafted the shape of the building along the border while saying that in this case, he “would be inclined... to have the kind of... building... maybe laid out, more, along the edge like that...” He continued by placing the entrance and the exit of the building at the beginning and the end of the shape and drew arrows and labeled them. Then he continued redrawing the entire shape of the building while claiming that “the whole building just becomes... more or less... a single loaded corridor...” “that privileges the water views.” After drawing an arrow representing the “water view,” he turned his attention towards the inside of the shape and began sectioning the shape by

drawing perpendicular lines to it while saying “we’ve got our rooms... maybe... lined up this way.”

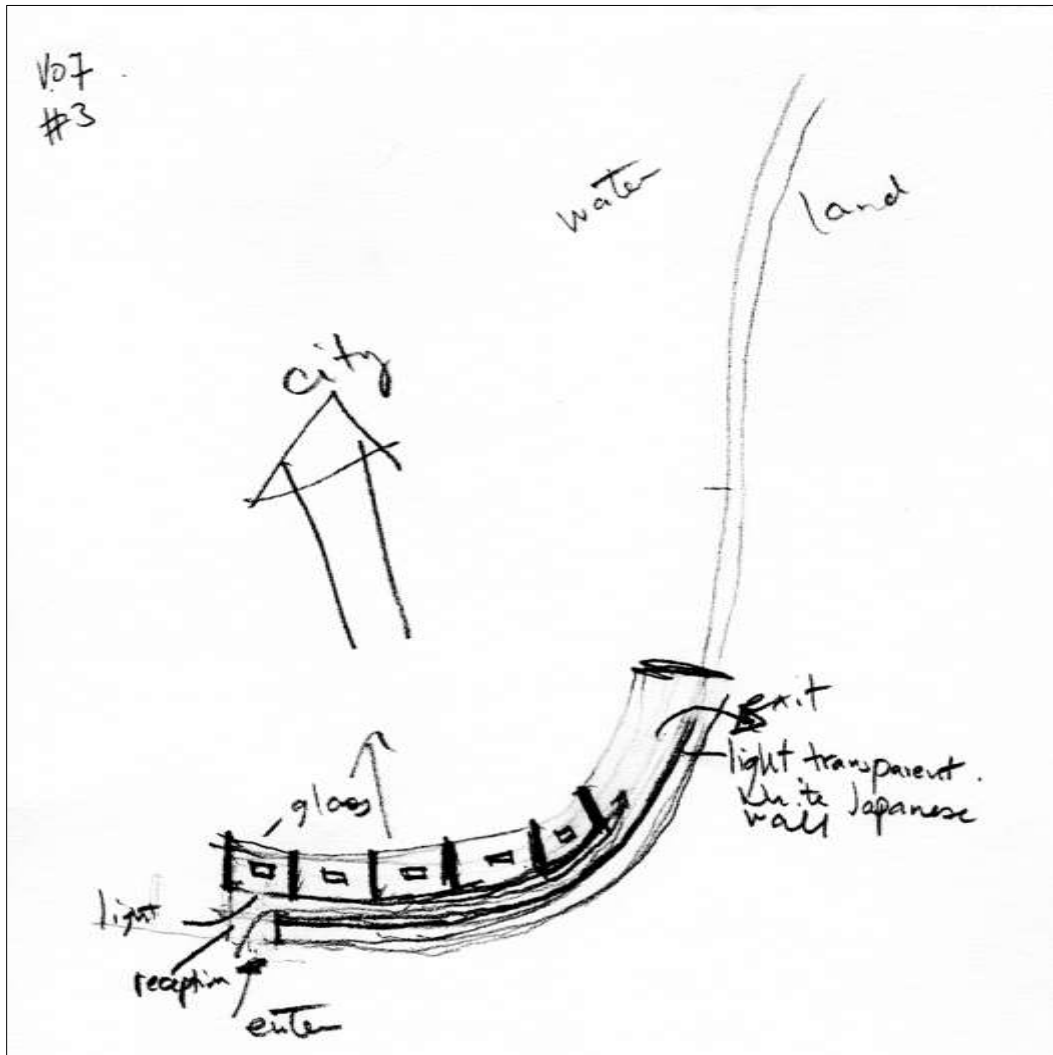


Figure 30: Diagram produced by participant 07.

Then, 07 drafted another parallel line along the shape of the building that left space for “the main corridor” before returning his attention to architectural elements and materials such as a “very light... transparent” wall and the need for a “water barrier” for it. From there, he went back to the rooms and using lines

and arrows mentioned connectivity issues among rooms inside the building while envisioning someone navigating such a sequence of spaces. After describing such navigation and the way people might perform the tea ceremony in these rooms, he ended the task by detailing inner walls made of glass and very light. In sum, the overall building shape emerged from the edge that separates the water from the ground. The layout of the building and architectural elements he envisioned emerged from such a line, and everything followed that order.

From the set of narratives presented above, we infer that although participants made design decisions based on several unique considerations, all of them made some design decisions in the same way, in light of similar issues. For one, the graphical tokens they used to render diagrammatic representations of their ideas were similar, as we expected for trained architects. Thus, the next sections present the outcomes that emerged after examining the graphical toolset of tokens used by volunteers and coding each utterance in their speech, and emergent issues related to design concerns that participants use to formulate their designs.

## **6.2 Graphical Toolset Used by Participants**

The revision of design processes presented in the preceding section introduces the graphical toolset used by participants to draw diagrams and sketches. Participants in the study were asked to draw rough sketches of their design ideas. Although no other specification was given, they made use of various types of representations, including bubble diagrams, arrows, written words, and



phrases to formulate their design ideas. They used these resources with typical architectural representations such as floor plans, sections, elevations, and perspective views. The use of views and perspectives relates, for the most part, to sub-episodes in which participants envisioned their designs or imagined specific views from inside their designs towards the outdoors. Participants used bubble diagrams to address programmatic issues such as positioning and scaling rooms and handling connectivity alternatives among spaces; the use of this kind of representation, however, was occasional. As stated, the set of graphical resources was very limited and consisted mostly of straight lines, open and closed shapes such as squares and circles, arrows, and written words as labels. Architects all over the world, since the first days of their training as future designers, learn to use these elements to draft and sketch design ideas.

The key point that emerged from the review of the design processes was that participants, indeed, used a discrete and limited toolset of graphical elements to formulate, test, and propose their designs. The meaning behind such elements, however, changed according to the participants' choices while they designed. Furthermore, the meanings behind graphical elements appeared to represent a discreet set of design issues that participants used to drive their design processes. Two tables support this observation. Table 16 presents the set of graphical elements used by the three participants in both teahouse tasks and Table 17

presents the set of issues that participants linked to the graphical elements they used.

**Table 16: Graphical tokens used by participants 01, 05, and 07 on each teahouse task.**

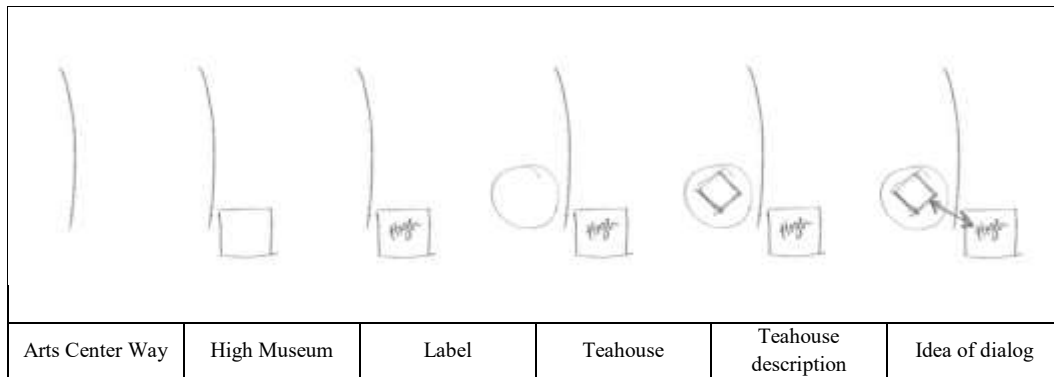
P01	US	Floorplan	<i>Line, square, label, circle, square, arrow</i>
		Floorplan	<i>Square, circle, label, circle, arrow, line, label, circles, rectangle, labels, lines</i>
		Floorplan	<i>Lines, square, line, square, lines, hatch, circle, line, hatch, labels</i>
		Floorplan	<i>Square, line, lines, hatch, line, square, lines, hatch, arrows, lines</i>
	NS	Floorplan	<i>Square, circle, arrow, circles, arrows, lines, lines</i>
		Floorplan	<i>Square, circle, arrow, square, square, lines, arrows, line, labels, hatch</i>
P05	US	Section	<i>Line, person token, line, line, label</i>
		Bubble	
		Diagram	<i>Square, arrows, bubble, bubble, bubble</i>
		View	<i>Line, line, line, lines</i>
		Floorplan	<i>Line, line, arrow, line, wavy line, arrow</i>
		Floorplan	<i>Closed shape, bubble, line, arrow, wavy line, lines, arrows, open shape</i>
		Floorplan	<i>Lines, line, arrow, lines, wavy line, arrows, lines, rectangle, labels, arc, arc, lines, square, arrows</i>
		View	<i>Lines, rectangle, wavy line, lines</i>
		Floorplan	<i>Arc, lines, wavy line, lines, line, arrows, lines, doodles, lines, square</i>
		View	<i>Arc, line, arc, lines, doodles, lines, wavy lines, lines</i>
	NS	Floorplan	<i>Lines, bubbles, rectangle, bubbles</i>
		View	<i>Lines, person token, lines, lines</i>
		Floorplan	<i>Lines, arrow, lines, lines, arc, lines, tree tokens, lines, lines, arrows, lines</i>
P07	US	Floorplan	<i>Line, line, line, label, labels, arrow, label, lines, tree tokens, label, lines, arrow, lines, rectangles, section line</i>
		Section	<i>Line, person token, lines, line, labels, line, label, arrow, line, line, doodles, lines, doodles</i>
	NS	Floorplan	<i>Line, labels, line, line, arrow, labels, arrow, lines, lines, labels, rectangles, lines, label, arrows, lines</i>

**Table 17: Meaning of graphical elements used by participants 01, 05, and 07 on each teahouse task.**

P01	US	Floorplan	<i>Street, museum, site, teahouse, dialog idea</i>
		Floorplan	<i>Building, entrance, main space, threshold, rooms, walls</i>
		Floorplan	<i>Site, museum, teahouse, pathway, main space, threshold, gardens</i>
		Floorplan	<i>Building, entrance, pathway, inner walls, main space, rooms, connectivity, inner walls</i>
	NS	Floorplan	<i>Building, entrance, connectivity, building shape, walls</i>
		Floorplan	<i>Building, entrance, circulation, room, room, view, connectivity, inner walls, gardens</i>
P05	US	Section	<i>Ground line, Persons, Label, Architectural elements (Roof, walls, openings)</i>
		Bubble	
		Diagram	<i>Bubbles, arrows, square shapes (boxes)</i>
		View	<i>Outside view: Terrain slope, trees, building</i>
		Floorplan	<i>Site, view, trees, view</i>
		Floorplan	<i>Corner, teahouse, circulation, view, trees</i>
		Floorplan	<i>Site, circulation, entrance, rooms, connectivity, main space, trees, view, outdoor</i>
		View	<i>Inside view: Walls, window, view, walls</i>
		Floorplan	<i>Walls, entrance, main space, views, trees, connectivity</i>
		View	<i>Inside view: Walls, Window, view, walls, main space</i>
	NS	Floorplan	<i>Lagoon edge, steps, pathway, main space, connectivity</i>
		View	<i>Outside view: Pathway, person, walls</i>
		Floorplan	<i>Lagoon edge, walls, trees, entrance, circulation, inner walls, view, connectivity</i>
P07	US	Floorplan	<i>Site, topography, entrance, noise, section, view, courtyards, rooms</i>
		Section	<i>Ground line, person, Label, Arrows, Architectural elements, (Roof, walls, openings)</i>
	NS	Floorplan	<i>Lagoon edge, building shape, entrance, exit, inner walls, view</i>

In both tables, TU stands for the teahouse in the urban setting, and TN the teahouse in the natural setting. Graphical elements appear in the table following the order in which participants drew them.




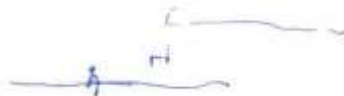







Tables 16 and 17 allow a comparison of the set of graphical elements and the set of meanings that such elements convey. Thus, straight lines usually depict architectural elements such as walls, building envelopes, and pathways in floorplans, but ground lines, walls, and roofs in section diagrams. Open and closed shapes are mostly used in floorplans and bubble diagrams and denote spaces and rooms related to the architectural program. Arrows usually render circulation fluxes or views towards where arrows are pointing. To a lesser extent, participants also used architectural graphic tokens to represent people and trees. What varied among the diagrams of participants in the six design processes was (1) the number of graphical tokens they used and (2) the types of problems they chose to address by drawing such graphical elements. It was also observed that participants bound meaning to graphical elements in flexible and diverse ways. While sometimes a line represented a wall, other times it represented a street, a pathway, or a buffer. To exemplify such differences Figures 31 to 34 show screen captures and reassembled images depicting the way in which participants built their design diagrams. These figures point out the relationship between graphical elements used by participants and the meaning they convey. Figure 31 shows the first diagram made by participant 01. The diagram consists of six traces: a line, a square, a label, a circle, another square, and an arrow.



**Figure 31: Traces and meanings for P01's first diagram.**

The first line represents Arts Center Way, a site border that caught the attention of participant 01. Then she drew a square representing the High Museum, labeled it, and continued by drawing a circle representing the site. Then she drew a square inside the circle while speaking out loud that it was the teahouse, and finalized her diagram by drawing an arrow to represent her idea of a dialog between both squares: the one representing the High Museum, and the other representing her teahouse. Thus, in her diagram, the line represented a street, closed shapes represented buildings and the site, and the arrow the design intent of establishing a relationship between the two buildings.

Figures 32 and 33 present the first diagram made by participant 05. The diagram, a section, renders the participant's belief of what was required for "a sacred tea space." She drafted the section diagram by first tracing a line to represent the ground level and continued by drawing a person token over the "ground line" and by tracing a second line depicting a roof, which was parallel to the ground line. Then she sketched vertical lines representing walls and connected the ground line and the roof. Then she drew what she called "two minor spaces," or two rectangles,

Ground line	
Person token	
Entrance	
Roof	
Wall	
Ground line extension	
Compression	
Release	
Wall	
Roof	
Sacred space	

**Figure 32: Participant 05's first diagram, resembling an architectural section.**

each time by initially drawing lines representing roofs and then lines representing walls. She ended the DE by writing the word "sacred" and verbally reinforcing such a character once again for the designed space. Figure 35 presents a reconstruction of the section diagram she sketch and the meaning behind each trace she drew. Figure 36 presents, on top, the finished section diagram, and below it, the graphically represented main ideas: a procession, a compression-release space, and a sacred space at the end of the path. The figures illustrate how participant 05 proposed and tested metric relationships among various spaces while drawing a few lines and then constructed a representation that matched the idea of the “progression of spaces.” Interestingly, by representing both ideas of the scale and of the progression of spaces graphically, she also established these two thoughts as primary design constraints. She used the construction of the diagram to formulate and depict her first design idea based on the notions of the progression and hierarchy of spaces (scale).



**Figure 33: Participant 05's first diagram and main design ideas.**

Participant 07 drew two diagrams to perform the task. He started drawing a floor plan, moved to a section, and after drawing the section, continued developing the floor plan. Figure 34 shows the first part of the floorplan construction.

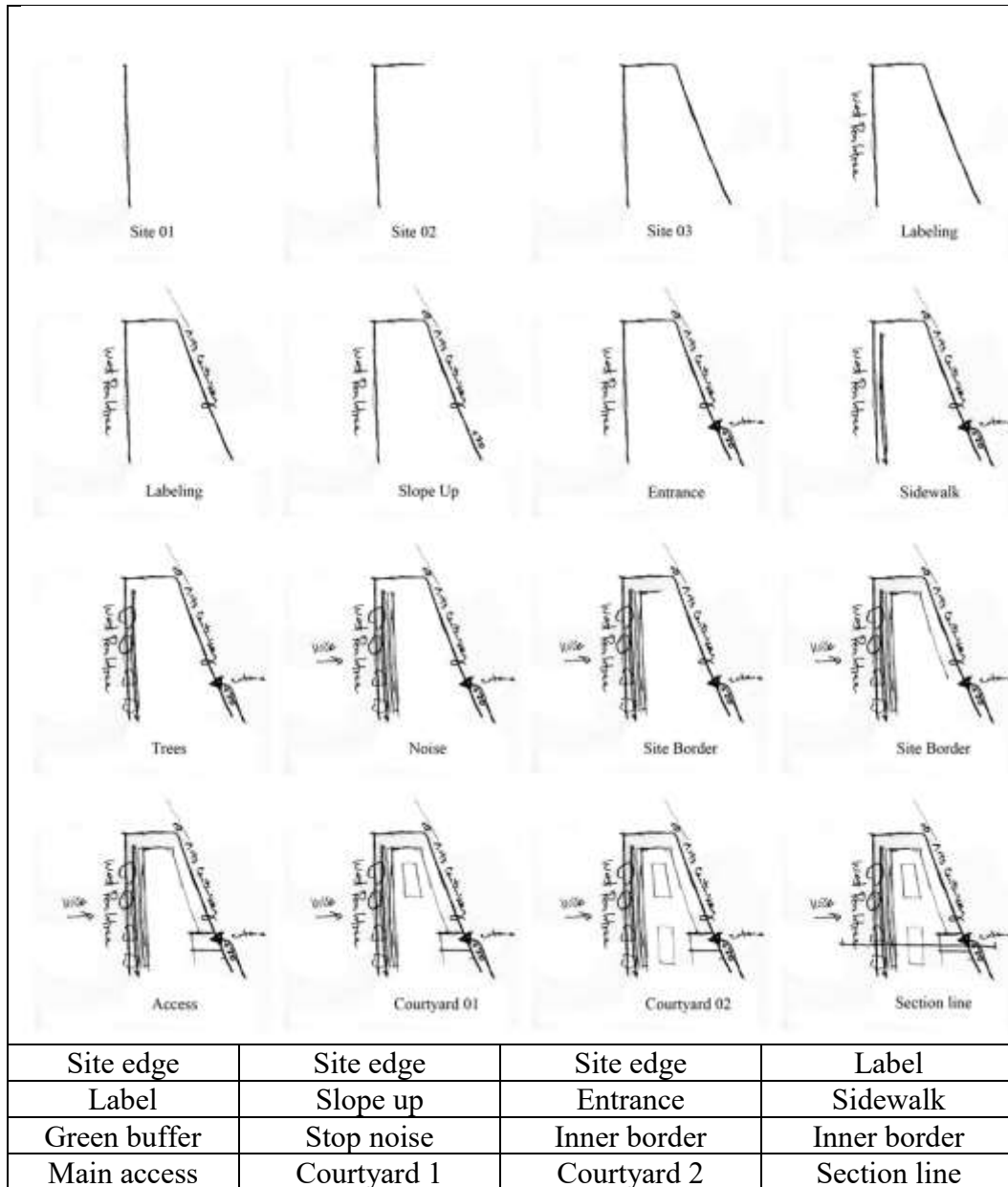


Figure 34: Participant 07 diagram and design ideas



His representation consisted mostly of straight lines and labels with an arrow and tree representations. With these elements, participant 07, like participant 01, rendered the site edges, the site entrance, the noise barrier, and the courtyards.

The three examples show that participants always used the same set of graphical elements when they began to tackle the design problem. Also, they also show that, while sketching floor plans, the participants drew from the outside to the inside. They repeated the same behavior on all of the diagrams resembling the floorplans they made. For instance, participant 07 began by delineating the edges of the site, continued to develop the drawing by moving inside the site to define the building placement, and completed the episode by deciding the location of the main entrance. Participant 01 did not draw lines for the edges of the site but started drawing a line rendering a street and square shapes resembling the envelope of the buildings. In her other diagrams, she started drawing lines for the shape of the building and continued drafting lines for inner walls and other architectural elements. Thus, while sketching floorplan diagrams, participants tackled and reduced the design problem from the outside to the inside, starting by delineating the site before moving inside of the site and start dealing with the teahouse.

Participants' use of section diagrams seemed to follow a similar logic. For instance, we observed that participant 05 always sketched sections by drawing the ground line first, followed by other straight lines for walls and the roof of the

building, similar to the logic of the construction for erecting a building. Another observation was that if participants began drawing on one side of the sheet and moved to the opposite side, they repeated the same pattern of occupation for the surface of the sheet on subsequent representations. Besides showing that architects, indeed, use a discreet and very limited set of graphical elements, along with specific procedures to arrange elements recalled from their stock of knowledge, this revision of drawing processes indicates that architects draw things that are not in their diagrams, and those things seems to play a significant role in the advancement of design processes.

These observations raised other important question: Why do they do that? From the data collected in this work, we cannot offer definitive or even plausible answers to these questions, but we can speculate that the use of a similar toolset is the result of the participants' training during their undergraduate programs. Architects all over the world learn to sketch these types of representations and elevate this knowledge at the level of skill. One possibility is that they learned to create these kinds of diagrams in a specific order. However, if so, it still does not explain the logic behind why their designs moved from the outside to the inside or why they erected walls before the roof; in other words, what drives the process of drawing such diagrams? Why is it that design movements follow the logic of outside to inside? After all, we may have expected that they randomly draw diagrams. As far as we know, no evidence has shown that architects learn to draw

floorplan diagrams from outside to inside. Indeed, the use of bubble diagrams, as those drawn by participant 05 (after drawing the section diagram presented in Figures 35 and 36), indicates that architects can think about the inside of the architectural problem without thinking about the outside. Another plausible explanation is that they tackle the site as a set of constraints already given to them (they cannot change the site) before moving to the inner architectural problem.

In any case, what the observations reveal is that participants use a discrete and limited set of graphical elements and combine them, as one does letters in the alphabet, to form architectural representations and to formulate architectural designs, which provides evidence that sketches, as many have claimed, are reasoning devices. From our observations, we also infer that the participants perceived different visual information from similar graphical elements they used; thus, we would like to determine if such information was relevant for the architectural formulation problem, as Keehner and Hegarty have suggested (2008).

Another consideration that emerges from the analysis relates to the notion that architectural formulation is a situated practice. Results of the analyses did not reveal what role the setup of the task and the materials played in the design processes. Hence, we cannot deny or argue in favor of "the contribution of structure in the environment, in artifacts, and in other people to the organization of mental processes" (Hutchins, 1995). After all, as Hutchins suggested, we have no way of measuring how people "offload cognition onto external aids, rather

than performing internal computations” (Hutchins, 1995). Thus, our analyses seem to reveal that the content, the set of issues that participants had in their minds, was the driving force behind their design processes, and drawing lines, shapes, and arrows acted as recording processes that facilitated the monitoring and the evaluation while mental associations took place in the minds of the architects. These observations provide support for the claim that design expertise consists of learning specific procedures that can be executed with a specific set of tools.

To complete the overall picture of reasoning processes in the architectural formulation, the next section presents the outcomes obtained after revisiting the six selected cases and coding them at a finer level of granularity. Such information complements the observations and ideas gathered from the participants regarding the way in which they use graphical toolsets to reason and to formulate their designs. These two pieces of information enable us to draft an approach that leads to a greater understanding of how sketches, diagrams, and drawings, as specific kinds of external representations, interplay with mental content to guide the emergent process of architectural formulation.

### **6.3 Inside Design Episodes**

As stated, DEs are key units of analyses that this study assumes to be responsible for moving the design process forward. The account of DEs presented in Chapter 5 indicates that although the participants’ use was random, they somehow tended to recall and address similar concerns when elaborating design

episodes. Thus, to identify a set of common representations that comprise the architects' stock of knowledge, we performed two cycles of codification to identify changes in participants' objects of attention at any moment during the design process. The intention was to capture the mentioned content of participants that prompted them to make revisions when they experienced DEs and then to observe and record their movements across and within the DEs. This aim stood on two premises: first, that a common set of knowledge representations, indeed, exists and constitutes the architects' stock of knowledge; and second, that knowledge representations operate inside DEs according to the logic of lateral and vertical movements and consequently move design processes forward. Thus, this subsection presents outcomes attained after analyzing the content that the three architects spoke aloud during the six design processes presented in this chapter. The analysis also takes design movements that occurred between DEs into account and patterns that emerged based on the repetition and the frequency of common issues mentioned by the architects.

#### 6.3.1 DE Subcategories

Table 18 summarizes outcomes attained after the second cycle of coding. These outcomes show that participants considered different matters when they formulated their designs and faced each task by addressing various concerns. Participants recorded significantly more or fewer shifts in attention (or focused on significantly more or fewer issues of concern) in at least one the subcategories than they did in others, but they exhibited no appreciable difference in the number of concerns that they focused on among the six tasks. Further, from these results,

we could formulate hypotheses about participants' performance by examining the subcategories of DEs that they exhibited during the design processes.

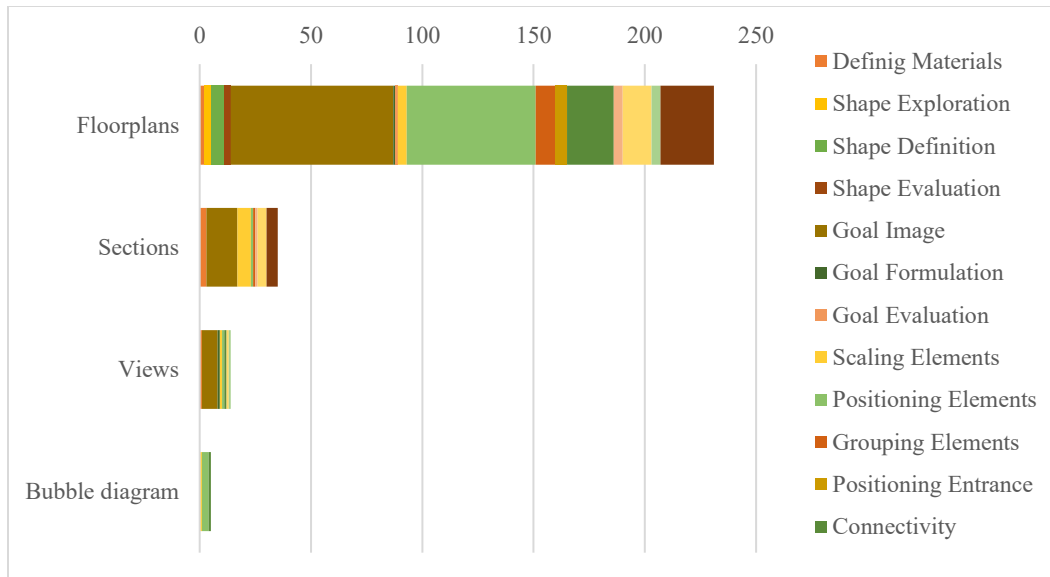
**Table 18: Coded DE subcategories**

Border Condition	3	0	6	2	13	4
Topography	0	0	1	0	4	0
Views	0	0	10	3	3	1
Circulation Patterns	0	0	0	4	1	0
Placing Elements	9	9	20	11	6	4
Scaling Elements	0	0	5	1	4	2
Connectivity	4	2	5	6	1	7
Grouping Elements	1	2	1	0	4	2
Placing Entrance	0	2	2	0	1	0
Labeling	0	1	0	0	0	0
Goal Image	14	10	11	27	23	17
Goal Formulation	0	0	0	0	0	1
Goal Evaluation	0	1	0	0	0	0
Shape Exploration	0	1	0	0	0	2
Shape Evaluation	0	3	0	0	0	0
Shape definition	3	1	2	0	0	0
Defining Materials	0	0	1	0	3	1
Total	34	32	64	54	63	41
Participant - Setting	P01 US	P01 NS	P05 US	P05 NS	P07 US	P07 NS

During the six design processes, the participants consistently exhibited two subcategories of design episodes: goal images and placing elements. Goal images represent sub-episodes in which the utterances of participants indicate that they were envisioning images. The occurrence of these sub-episodes that occurred across all design processes indicates that envisioning images occurs regardless of the subproblem being undertaken. Thus, envisioning goal images can be understood as an inherent part of cognitive processes responsible for the formulation of architectural designs. Indeed, such a process may indicate the transformation of symbolic to pictorial representations and vice versa as well as

thinking about images. Along the same vein, at all points during their design processes, participants drew and positioned graphical elements on paper to create their designs. Indeed, placing graphical elements such as lines, open and closed shapes, and architectural tokens for persons or trees is an essential part of the formulation process that takes place regardless of the content that the architect is holding inside the mind.

As explained in the previous section, what is of interest regarding the use of these graphical elements is the meaning they convey, that is, what they represent, and not the shapes themselves. Thus, by placing graphical elements inside of and across different DEs, architects, represented by the participants in this study, settle on units of content that such graphical elements represent and build complex mental representations by adding and interweaving the meaning of such units and their relationships. Thus, a few lines or shapes become entities rendering elements, properties, and meaning, and even allow architects to perform mental simulations and test scenarios. Besides these two subcategories, which show a permanent presence in design processes, two other subcategories of DEs played a significant role in the participants' formulations: considerations about the borders of the sites (during the site episodes) and the examination of connectivity among spaces (during the programmatic episodes). These two subcategories appeared on all of the six design processes analyzed, suggesting that they are also a main concern of architects formulating their designs. Lastly, seeking patterns that may shed light on the relationship between DE subcategories, we analyze the intersection between drafting episodes and subcategories. Figure 38 presents subcategories and drafting episodes.



**Figure 35: Diagrams and subcategories**

Figure 35 presents the results of such analysis and reveals that the use of floorplans dominates design processes regardless of the matters architects consider while formulating their designs. The use of floorplans dominate these participants' design processes, including the emergence of subcategories identified within the DEs. Therefore, the claim that the use of floorplans is apparently not related to the nature of the matters architects chose to address when formulating their designs may be valid. Thus, floorplans act, instead, as recording devices that allow architects to keep track of their design decisions, evaluate them, and monitor their advancement during the design process.

Since this analysis revealed that the participants took the remaining subcategories into account in a random fashion, with some categories barely considered or even not considered at all, the author of this study performed a final cycle of open-ended coding analysis while seeking the architects' common stock of knowledge. From such a revision emerged a set of concerns that participants



constantly access to formulate their designs. This research called such concerns "design issues."

### 6.3.2 Design Issues

The analysis of the six design processes presented in the introduction of this chapter found that participants elaborated on several common design issues (DIs) while working during the various DEs. Specifically, the objective of the revision was to reveal a set of common representations that underlie DIs and identify patterns in the use of DIs that participants exhibited while formulating their designs.

Three key observations of how the participants handled Dis emerged. One was that participants focused their attention on similar DIs. Indeed, this analysis demonstrated that participants considered 28 common DIs in the six design processes. Another is that a DI appears to have two components: knowledge representations, which appear to be semantic in nature but also act as units of content; and a set of representations that act as operations. The analysis also enabled us to infer that participants, besides recalling, at their discretion, knowledge representations as content, mixed similar units of content and operations to make design decisions. Three tables summarize and support these observations. Table 19 presents design issues detected in each one of the six cases. Table 20 presents the number of occasions in which participants recalled different DIs and the overall percentage of their occurrence. Table 21 presents the separation of content and the operation observed for each detected DI.

**Table 19: Summary of DIs considered by participants 01, 05, and 07 in the designs of both teahouses.**

	P01	P05	P07
Teahouse in Natural Setting	ceremonial space location building shape ceremonial space location entrance location room location room connectivity building shape room location room connectivity room location entrance shape	border condition - pathway border condition - views preparing site ceremonial space location building shape building location ceremonial space views room location entrance envisioned room connectivity garden location circulation pathway entrance envisioned room connectivity room location architectural elements - location architectural elements – materials	border condition - site shape building shape buildings envisioned building views room location room connectivity architectural element - materials architectural element - materials room envisioned room location room connectivity architectural element - materials architectural element - materials
Teahouse in Urban Setting	border condition element building location entrance location ceremonial space location room location architectural element location building location pathway location garden location entrance shape ceremonial space connectivity room location room connectivity	ceremonial space - envisioned entrance location entrance connectivity natural condition - topography border condition - trees room location border condition - urban front entrance location garden location ceremonial space views room location room connectivity room views room views ceremonial space views ceremonial space envisioned ceremonial space connectivity architectural element - location architectural element - materials	natural condition - topography border condition - streets entrance location natural condition - topography entrance location building envisioned architectural elements envisioned entrance location border condition - site edge border condition - streets entrance location architectural element - placement ceremonial space envisioned architectural element - materials ceremonial space views buildings envisioned room location architectural element - materials
NS	10	17	13
US	13	19	18

Table 19 shows that room location was the DI that participants recalled the most, followed by entrance location, connectivity among rooms, and definition of materials for various architectural elements. Room location emerged as the most common DI that participants took into account because the three of them, at some

point in their design processes, drew arrangements of rooms and spaces, that is, floorplans, as the main diagram driving their design processes. After all, as previous results in this research have shown, participants made five times as many floorplan diagrams as any other type of diagram and spent more than half of their time formulating their design proposals while elaborating on this type of diagram. However, the recurrence of material definitions for architectural elements such as walls, ceilings, and pavements indicates that participants tended to recall such knowledge representations towards the end of their design processes, usually in a rush while wrapping up their design proposals. For instance, in the case of the teahouse in the urban setting, participants 05 and 07 followed that pattern while volunteer 01 considered the definition of materials in the middle of her design process. Although these observations may have had to do with the fact that this was a schematic design project, not an executed design, they still reflected the way in which architects formulated their designs.

Overall, these observations provide evidence of the claim that participants used a small and discrete set of DIs to formulate their design proposals, and by selecting to face such DIs, they advanced the formulation of their designs even if the design task was unfamiliar to them, as was the case of the teahouses.

Also, these results constitute evidence for the claim that DIs working out programmatic relationships such as the location of rooms, the main entrance, and connectivity among spaces are the most essential drivers guiding design formulation processes.

**Table 20: Design Issues and the number of time participants recalled each DI.**

<b>Design Issues</b>	<b>Count</b>	<b>%</b>
Room location	12	13.2
Material definition	8	8.8
Entrance location	8	8.8
Rooms connectivity	8	8.8
Architectural element – location	4	4.4
Border condition envisioned	4	4.4
Building shape	4	4.4
Main space location	4	4.4
Main space views	4	4.4
Border condition element	3	3.3
Buildings envisioned	3	3.3
Building location	3	3.3
Garden location	3	3.3
Main space envisioned	3	3.3
Site's topography recall	3	3.3
Entrance envisioned	2	2.2
Entrance shape	2	2.2
Main space connectivity	2	2.2
Rooms views	2	2.2
Architectural element - envisioning	1	1.1
Border condition shape	1	1.1
Border condition views	1	1.1
Building views	1	1.1
Circulation views	1	1.1
Entrance connectivity	1	1.1
Pathway locations	1	1.1
Rooms envisioned	1	1.1
Site envisioned	1	1.1

As stated previously, another consideration that emerged from this analysis relates to the content of DIs. We observed that DIs possess two components: units of content and operations that drive such content. Specifically, the revision revealed 12 knowledge representations identified as units of content,

and eight knowledge representations identified as operations. Table 21 presents the set of units of content and operations observed, and the total number of times participants took each one of these representations into account. The table also shows the probability of recurrence based on the total number of repetitions observed.

**Table 21: Units of content and operations observed within DIs.**

<b>Units of content</b>	<b>Count</b>	<b>Prob.</b>	<b>Operation</b>	<b>Count</b>	<b>Prob.</b>
Rooms	23	0.25275	Location	35	0.38462
Entrance	13	0.14286	Envisioning	15	0.16484
Main space	13	0.14286	Connectivity	11	0.12088
Building	11	0.12088	Views	9	0.0989
Site border	9	0.0989	Definition	8	0.08791
Materials	8	0.08791	Shape	7	0.07692
Architectural elements	5	0.05495	Element	3	0.03297
Gardens	3	0.03297	Recall	3	0.03297
Site's topography	3	0.03297			
Circulation fluxes	1	0.01099			
Pathways	1	0.01099			
Site	1	0.01099			
<b>Total</b>	<b>91</b>	<b>1</b>	<b>Total</b>	<b>91</b>	<b>1</b>

From these observations, we can infer that units of content and operations map to each other one to one or one to  $n$ . Thus, while units of content are objects on which participants focused their attention at any one time, operations were performed on such units of content. During this stage of analysis, observations revealed that participants used “location” as an operation to create and to evaluate design decisions for different units of content such as rooms, entrances, main spaces, buildings, architectural materials, garden areas, pathways, and so on. In general, the operation of “location” indicated that the participants had to place the

unit of content somewhere in the diagram they were drafting. Along the same vein, the operation of “envisioning,” which indicated that participants visualized units of content, was observed in two modalities: non-present, when participants held such visualizations in their minds and were talking aloud about them; and present, when participants were drawing and looking at such units of content. Another interesting observation was that “envisioning” units of content typically triggered mental simulations in the participants’ minds. Such simulations related to the behavior of the unit of content participants held in mind or the experience of users as they navigate the spaces being designed. Participants used “connectivity” to evaluate the adjacency of units of content and the accessibility of one unit to another and “views” to recall lines of sight from and towards the units of content. In the set of design processes that were reviewed, participants considered views from the different rooms of their teahouses towards outdoor spaces (P05) and the skyline of the city (P01 and P07). Participants used the operation of “definition” to specify materials, that is, “architectural elements,” the only unit of content linked to this operation. “Shape” involved the generation and the evaluation of graphical elements in the diagram representing physical forms being addressed in the design process, and strikingly was not observed as one of the top operations used. Such an observation may imply that most architectural formulation processes relate to different DIs besides evaluating the design outcome that is taking form on paper. The fact that participants barely made statements regarding the shapes they were drawing does not imply that they were still evaluating them silently. For instance, they may have evaluated, among others, the aesthetic appeal of the arrangement of shapes, the degree of symmetry

of the diagram, the degree of organization of the diagram, or its complexity, the operations of which can be executed wordlessly. The data collected in this study, as well as the techniques of analyses used, are not amenable to observation whether or not such evaluations occurred or not.

“Element” indicated that a specific element was recalled with a unit of content. The use of this operation suggested that participants made an evaluation or a comparison between the element and other units of content even though, on several occasions, the specification of elements emerged just as a reminder, and the participant did not use it to make any design decision. Lastly, the use of the category “Recall” referred explicitly to participants’ remembering the topography as an issue they had to take into account. Participants 05 and 07 mentioned such issues in the task in the urban setting, and P07 took it into account in his decision as to where he would place the main entrance to his proposal.

It is worth repeating that participants did not use this set of operations in a straightforward fashion and for one unit of content alone. As previously stated, units of content and operations overlap, but they also operate on a one-to-*n* modality, entangling a flux of mental operations and mental content that drives the design formulation process. Thus, for instance, participant 01 used several utterances codified in various categories to discuss her building location. She used one utterance to mention the High Museum near the site, another to mention the site borders (West Peachtree and Arts Center Way), another to mention the topography, another to say she was trying to find the best location for the main entrance, another to state that both programs, the tea house and the High Museum, were “cultural things,” and so on. She continuously refocused her attention from

one object of attention to another, each belonging to a different DE. She did so while building her argument for her design decision of placing the building in the center of the site, which she stated as a kind of dialog between the tea house and the High Museum “where this kind of... speaks to that.” We consistently observed that when facing, formulating, or considering DIs, participants focused their attention on a central unit of content and used other units of content to reinforce design decisions and to perform mental simulations or mental evaluations regarding the central unit of content in the DI.

The objective of this discussion was to discover the set of typical DIs comprising the participants’ stock of knowledge—DIs that they used to address the formulation of their architectural proposals. As stated in Chapter 5, the first cycle of coding allowed observations of volunteers handling several issues while formulating DEs. Thus, following new and meticulous observations of participants’ design processes, DIs emerged as the key units of knowledge that architects used to formulate their designs. Such outcomes contribute two important ideas to this study: first, the idea that DIs are cognitive artifacts composed of semantic representations and operations; and second, the idea that architects draw from a discrete set of DIs for most of their design decisions. The next subsection presents observations regarding how navigation among DIs takes place. Such navigation was recognized as design movements.

### 6.3.3 Design Movements

Changes from one DI to other exposed design movements are assumed to be the result of changes in participants’ focus of attention. This section reports



design movements observed at three levels of granularity: for subcategories, for subcategories within DEs, and for subcategories within DIs. During these observations, design processes were individually identified, allowing for a comparison among them. In all of the tables that accompany this subsection, US stands for “urban setting” and NS for “natural setting.” First, Table 22 summarizes the total count of design movements among subcategories that participants made on each task.

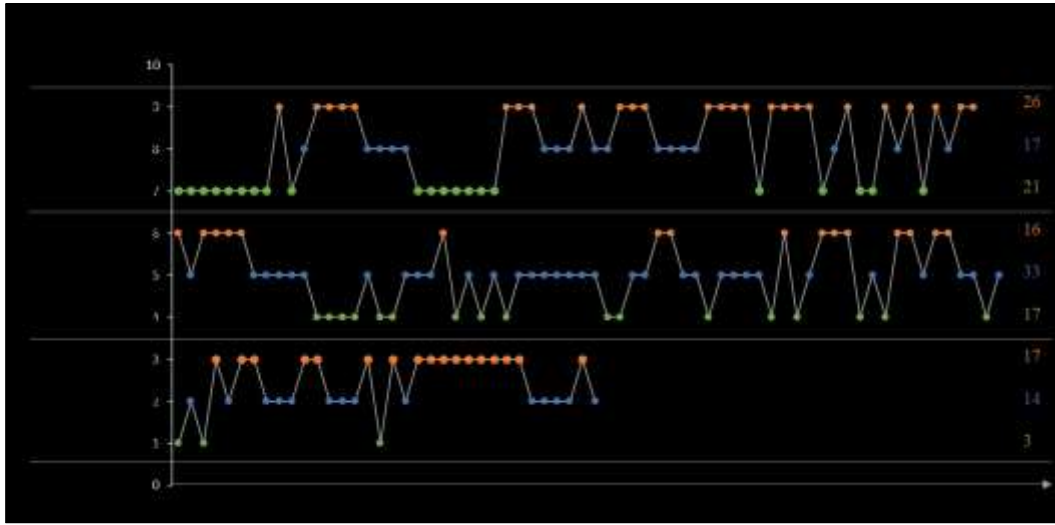
**Table 22: Account of design movements made by participants P01, P05, and P07.**

	P01	P05	P07
US	33	65	63
NS	31	53	40

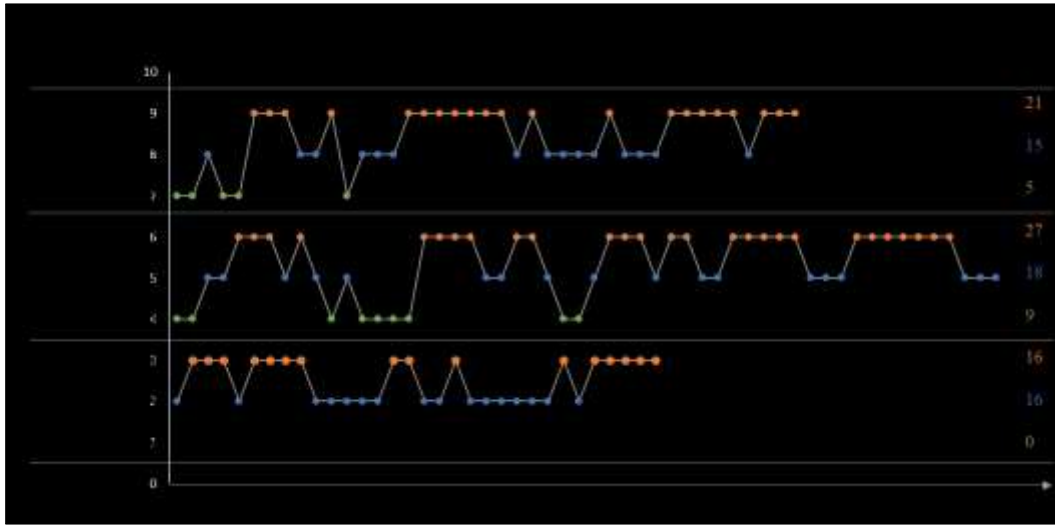
The table shows that participants experienced more attentional shifts facing the teahouse in the urban setting than in the natural setting. Although this difference could be random, it might also suggest that participants were more familiar with the urban site or that they had more tools in their toolkits to represent urban settings. This observation is important because one of the critical concerns of this study is to identify differences in the common stock of knowledge used by architects when they address site matters. As a reminder, it was assumed that architects use similar knowledge representations to address site issues. However, the comparison of DIs and subcategories in which participants embedded their concerns when addressing site matters indicates that they randomly choose which site concerns to address. The table also shows that participants P05 and P07 engaged in more design movements than participant P01 to formulate their designs, which matches the scores assigned by judges.

To shed light on these speculations, Figures 36 and 37 render design movements related to SE, PE, and BICE. Figure 36 presents the total number of design movements that participants P01, P05, and P07 made while performing the task of the teahouse in the urban setting. Likewise, Figure 37 presents the design movements observed in the three cases in the natural setting.

In both figures, the x-axis represents time, and colored dots in the y-axis represent utterances, coded as SE, PE, and BICE. More importantly, each dot represents a subcategory, and edges among the dots represent design movements. The number on the right presents the total number of subcategories observed in each DE. Thus, for instance, we observed that participant P01 began the task in the urban setting saying out loud an utterance regarding the site and a second utterance regarding the program. Then her attention returned to site concerns, and from there, she moved to the BICE idea, returned to a programmatic consideration, and so on.



**Figure 36: Comparison of the design movements for the teahouse in the urban setting**



**Figure 37: Comparison of the design movements for the teahouse in the natural setting**

Thus, Figures 36 and 37 provide a comparison between the sequence and the total count of subcategories by participants. From such a comparison, we observe that participants recalled similar concerns on separate occasions.

Lastly, Tables 23 and 24 present, according to the logic of lateral and vertical movements adopted by this research, design movements for DIs and

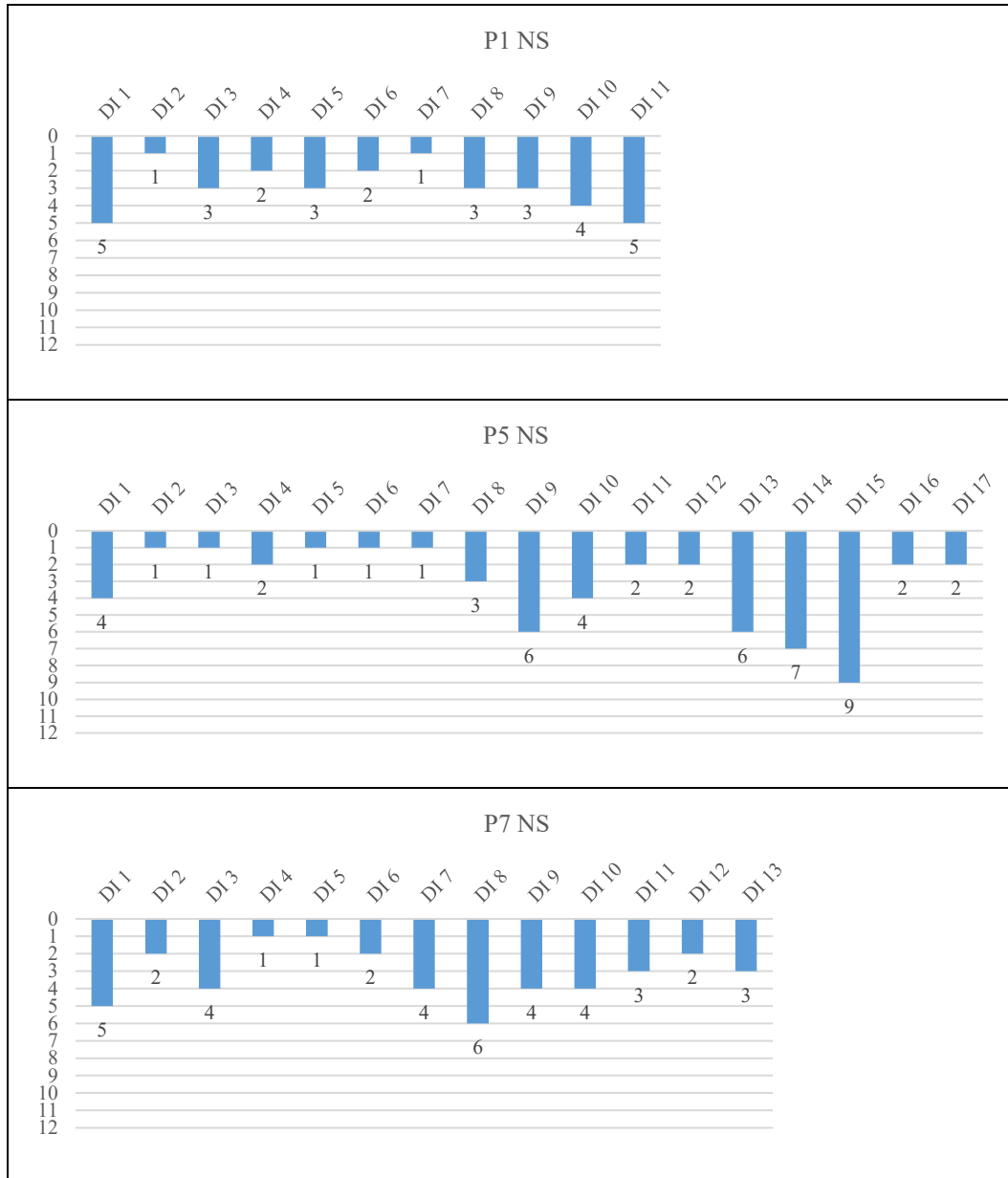
subcategories coded within the design processes. DIs count for lateral movements since they are more complicated units of analysis than subcategories. Indeed, DIs gather various utterances that capture one or more subcategories. Consequently, subcategories, which count as vertical movements, were mapped within the DIs.

Tables 23 and 24 show, in light of vertical and lateral design movements, individual differences across participants. Such differences may explain their differences in design performance. Table 23 shows that, for the task in the urban setting, while participant 01 went through 13 DIs (lateral movements), reaching up to five levels deep (vertical movements). Participants 05 and 07 experienced 19 and 18 lateral movements and 11 and 10 vertical movements, respectively. Likewise, Table 24 shows, for the natural setting, that participant 01 developed 11 lateral movements and up to five levels of vertical movements whereas participants 05 and 07 unfolded 17 and 13 lateral movements and up to nine and six levels deep, respectively.

**Table 23: Participants' lateral and vertical design movements for the task in the urban setting.**



**Table 24: Participants' lateral and vertical design movements for the task in the natural setting.**



Most likely, the decline in the number of lateral and vertical movements from one setting to the next may have obeyed a task order since, indeed, these

three participants began by performing the task in the urban setting (the first task for participants 01 and 05, and the second for 07), and later the task in the natural setting (the fourth task for participants 01 and 05, and the third task for 07). As stated previously, cognitive fatigue and information already loaded into the working memory could have played a role in these participants' performance, who produced richer design processes in the case of the urban task.

Lastly, from these comparisons, we can infer that, regarding the role that the number of design movements may play for architectural formulation, the richness of design processes may be rooted in the number of issues considered as well as the way in which they interwove. Thus, two key concepts emerge from this analysis: the variety and the density of DIs considered by participants while formulating their designs.

#### 6.3.4 Variety and Density of DIs

As design episodes (DEs) did not capture the richness, complexity, and specific units of content used by participants within the episodes. DIs were identified because As stated, this research assumes that such content plays a significant role; that is, it is key to architects' elaborating units of content that guide the formulation of architectural design problems. Following the review of the account of DIs and design movements, the two concepts of variety and density emerged. Variety indicates the number of different DIs recalled by participants, and density indicates the overall number of DIs. Density also represents the number of shifts among the DIs. Table 25 summarizes variety and density and the judges' scores on the six tasks reviewed in this chapter.

**Table 25: Correlation and comparison of variety, density, and judges' scores.**

Participant - Task	Variety	Density	Judges' Scores
P01 - US	11	13	1.94
P01 - NS	6	11	2.06
P05 - US	14	19	4.13
P05 - NS	14	17	4.31
P07 - US	11	18	4.13
P07 - NS	10	13	3.56
<i>Correlation</i>	0.72	0.85	

The resulting percentages from testing these two concepts with the judges' scores were high: 72% for variety and 85% for density. These findings indicate that design performance, indeed, relates to variety and density of DIs taken into account by architects. Moreover, these results suggest that the variety and the density of DIs used by architects formulating design problems are predictors of design performance.

## **6.4 Discussion**

Unfolding DEs allowed the observation of their significant components playing different roles and contributed to our understanding of architectural formulation. Such observations included an analysis of the graphical toolset used by participants, subcategories detected within design episodes, the emergence of design issues, a report of design movements, and the emergence of variety and density as matters taken into account by participants.

We could not observe links among the participants' construction of diagrams and the number of internal representations of design knowledge they used to tackle their design problems. However, the analysis of the graphical



toolset used by participants revealed that participants used a discreet and limited toolset of graphical elements to formulate their designs. Further, the analyses also revealed that the meaning participants assigned to graphical elements changed according to the participants' choices while designing. Tables 16 and 17 show such a contrast and provide support for claiming that the meanings that graphical elements convey are bounded to different design issues that participants used to drive their design processes. The relationship between graphical elements and the meaning they convey most likely is rooted in the fact that, at the neural level, perceptual and motor systems are interconnected and complementary with regard to grounding embodied architectural formulation as studies in cognitive science and cognitive psychology have suggested (Goodale & Keith Humphrey, 1998; Kozbelt, 2001; Seeley & Kozbelt, 2008). After all, we cannot avoid the fact that, as Emmons stated, "design drawing developed as an embodied activity" (Emmons, 2014, p. 538) that can be traced back to the Renaissance.

It is worthwhile noting that the participants addressed most DIs while engaged in floor- plan representations. Of course, they also used diagrammatic sections and scribbled notes, thus raising the following questions: What is unique about floor plan representations? The answer may lie in a large number of PEs detected, which suggests that architectural design formulation is to a great extent a matter of topological relationships among units specified in the design brief. Nevertheless, more than 50% of the time, participants engaged in developing floorplan representations.

The analysis of subcategories with DEs revealed that participants, as they begin to tackle design problems, largely rely on four subcategories of drawings:

goal images, element placements, site borders, and connectivity. Envisioning goal images occurs regardless of the task for design formulation and permits switches between the different modalities, pictorial or symbolic, of representations. The placement of elements also takes place regardless of the content in mind since, as demonstrated, a graphical element conveys a unique meaning or a unit of content. What is critical about placing elements, though, is that such drawing actions settle, step by step, the construction of the design diagram and register the design decisions made by the architect. Such drawing actions and design decisions emerge hand in hand with the construction of complex mental representations that, interwoven with other representations, allows the construction of the narrative that drives the design process. Besides envisioning goal images and placing elements, participants always attended to the site borders and connectivity issues among the spaces required by the brief, which suggests that architects use these two concerns as commodities when encountering unknown design problems.

The analyses also revealed that a discrete number of knowledge representations that this research refers to as “design issues” (DI) are a crucial component of architectural formulation. We observed that DIs garnered the participants’ attention in two ways. They became the major object of attention, acting as units of content that participants used to drive their design processes; or they were used as operations to be performed over the units of content. Specifically, the analysis revealed 12 units of content and eight operations that all participants considered and revisited while formulating their designs. The analyses did not capture the reasons why some DIs were worth exploring (vertical

movements) or why others entailed progression (lateral movements). Although this finding supports a lack of patterns regarding the use of common cognitive strategies that drive design formulation, the discrete number of DIs that emerged from the open-ended cycle of coding provided evidence supporting the existence of a discrete set of representations that constitute architects' stock of knowledge.

Design movements emerged hand in hand with DIs and appeared as other key components of DEs. Design movements represent the number of attentional shifts that volunteers made during their design processes while elaborating DEs. As Chapter 5 shows, even though the participants did not follow a specific order when presenting their DEs, the design movements occurring among and within episodes were responsible for moving their design processes forward. What was observed regarding design movements was that all of the movements related to design performance. Indeed, observations of participants 05 and 07 revealed that they considered almost twice as many design issues to work out their proposals as volunteer 01, and they were more proficient from the perspective of the evaluators. Hence, the analysis presented in this chapter indicates that design performance is linked to the density and variety of DIs. In other words, density and variety serve as predictors of design performance.

Interestingly, the concepts of variety and density have been previously addressed in the literature, albeit in a different way, mapping content to design diagrams. In particular, studies by Goel (1992a, 1995) and Bafna (2008) referred to the concept of “semantic density” used in previous studies. Goel used this term to refer to the specific property of ill-structured representation by which graphical tokens, representing the same entity, are closely similar to other tokens in other

versions, or variations, of evolving design diagrams. The key point made by Goel was that “semantic density,” among other properties, allows for the construction of a graphical representation of a design problem. Bafna, however, when discussing “the distinction between notational and imaginative use of drawings,” used the term “semantic density” to refer to the mapping process between graphical tokens and the meanings they convey. Thus, while Goel considered “semantic density” a property of graphical tokens in evolving diagrams, Bafna considered it a process of linking such tokens with meaning.

The comparison of the six design processes revealed that participants used different design strategies to approach the formulation of their teahouses. Participants started their design tasks by approaching, randomly, the site or the program, and in one case, by formulating a design goal (Participant 05 in the urban setting). These formulations revealed the use of analogical thinking as another strategy to approach design tasks. The use of this strategy is not new, and scholars have stated that it is a common approach to design tasks: producing design concepts that resemble the use of cognitive structures such as mental models (Ö Akin & Weinel, 1982). A well-known quote by Louis Kahn states that “Before a railroad station is a building; ...it wants to be a street; it grows out of the needs of the street, out of the order of movement” (Kahn, 1956). This quote beautifully exemplifies the use of this strategy. As Kahn’s words illustrate, design concepts easily emerge from the use of metaphors or analogies and serve to establish constraints that delineate the formulation of the design problem or sub-problems. Thus, reviewing the site and programmatic requirements of a building

and using metaphors and analogies are resources that architects use to devise sub-goals during their process of formulating an architectural project.

Thus, the analyses performed in this study suggest that architects can tackle any architectural problem by addressing known DIs or using analogical reasoning to produce an image or design goal that captures the character of a building. Although previous studies have reported design episodes and movements (Schön, 1987; Goel, 1995), such studies have focused on exposing the notion of motion or navigation among subproblems in design formulation. Goldschmidt (2014; 1991, 1997) also reported similar observations and developed the technique of linkography to render such navigation. However, to the best of our knowledge, these studies, nor any others, have exposed the nature of the content used by architects to formulate their designs.

## **CHAPTER 7 CONCLUDING REMARKS**

This dissertation presented a research study conducted with the aim of clarifying the role that procedural and semantic representations of knowledge play in the early stages of architectural formulation. To address such an aim, the dissertation presented a framework involving four topics. First, it reviewed the open-ended nature of design processes and presented foundational knowledge and broader views regarding the understanding of design activity as a type of ill-structured problem. Then, the dissertation examined three models that explain design processes, with a focus on the role that mental content and procedural strategies play in design formulation. The third section reviewed current trends about diagrams and sketches as cognitive artifacts play in architectural formulation. Lastly, the framework introduced design episodes as the key units of analyses used to inform this research.

After presenting a review of the literature, the dissertation proposed an observational inquiry of design processes and a protocol analysis approach as the primary technique for studying its subject matter. Fourteen volunteers took part in the study by answering a questionnaire, taking two cognitive tests, and performing four design tasks, which were the main component of the study. According to the research design, participant's design processes were recorded on video, and two judges, professional architects with an experience teaching design studio, evaluated each participant design processes as a measure of their design performance. The video files and transcriptions were used to run the protocol analyses and identify design episodes (DEs) within the design processes. Thus,

the dissertation analyzed the participant's design processes by associating the scores assigned by the judges as a measure of design performance and the findings that emerged from the analysis of the design processes.

It is worth noting that the framework of this study adopts the use of procedural strategies as a critical cognitive resource for building architectural conceptualization and that in such a framework the conditions provided with the problem—the site, the program, and the type of building—play a crucial role. It is also worth noting that the findings may not apply to other kinds of design processes, which are driven using computational design, physical models, or other approaches. We interpreted the results of this research according to these limitations. Thus, in three chapters the study examined these matters after carrying out the analyses of the datasets collected. The protocols analyses revealed that participants began tackling their designs by focusing their attention on three types of concerns regarding the site, the architectural program, and the building image and character. The constant appreciation of these three kinds of design episodes (DEs) exposed the episodic nature of design processes. Thus, the analyses yielded the following findings:

1. Design processes are episodic in nature.
2. Architects formulate their designs using three types of episodes along with a small set of graphical elements.
3. Episodes consist of well-defined sub-problems, in which architects work a set of specific design issues (DIs).
4. Variety and density of DIs can predict design performance.

### **7.1 On the episodic nature of design processes**

The analysis of the data confirmed that participants formulate architectural problems and navigate design processes by tackling subproblems rather than the main task. The subproblems observed belong to three categories which cluster a discreet set of architectural knowledge representations. Thus, by observing the way in which participants consistently break down the design problem into subproblems, the study confirmed that (1) the nature of design processes is episodic, and (2) that all participants' design processes were a continuum interlace of DEs (Table 9). The analyses also showed that DEs consist of well-practiced scenarios in which a sub-problem of the overall design task is treated as a well-defined problem (Figures 23 and Table 15). Moreover, the analyzes of DEs revealed a set of common units of knowledge that participants recalled, selected, and used to made design decisions. Such sets of units fell into three main categories; units of knowledge related to the site, to the organization of the architectural program, and to the construcion of the building's image and character.

Further, the analysis of the way in which participants navigated DEs revealed how these units of knowledge map onto the graphics elements that architects draw while drafting an external representation (Tables 16 and Table 17). Notably, we observe how external representations capture the most salient features of declarative knowledge that participants had in their working memory and with which they were seeking to formulate a solution for sub-problems in DEs. Moreover, our observations allow us to theorize that the uniqueness of design outcomes stands on a myriad of topological arrangements that permit



endless possibilities of configurations thanks to the set of declarative representations used to bound meaning to the arrangement of graphical elements depicted in Table 16.

Lastly, is essential to remind that the results of the questionnaire showed that all participants were qualified to perform the design tasks using diagrams and sketches as the only medium of work. Also, the results of both psychometric tests indicated that participants performed as expected, demonstrating average performance on Analogy Test A and expert performance on the Spatial Aptitude Test. Correlation tests were used to test relationships among scores assigned by the judges and the outcomes of both psychometric tests and to verify if the years of experience participants declared on the questionnaire might have affected such scores. Surprisingly, the results of the tests exposed a weak relationship between the evaluations of the judges and the scores of the participants on both psychometric tests and no relationship between judges' evaluations or years of experience (Table 8).

Overall, the implications of these findings indicate that the early formulation of architectural design lies in the interplay of three kinds of architectural sub-problems that architects learn to use and the topological configuration of graphical elements selected to build a representation of the sub-problem.

## 7.2 Types of episodes

Participants started the formulation of their designs by considering site or programmatic matters, some of which they defined as design constraints. We observe four ways in which architects used such site matters. (1) By recalling and analyzing their knowledge about how to treat the site's "borders," (2) the circulation patterns, (3) the natural conditions (e.g., the topography, the sun path in the sky, or ventilation fluxes), and (4) the site's views. We also observe that when dealing with programmatic requirements, participants mainly addressed (1) the positions of rooms, (2) connectivity among spaces, and (3) the location of the entrance.

Outcomes of the analyses also revealed an absence of patterns regarding the association of drafting episodes and the three major types of design episodes—site episodes (SE), architectural program episodes (PE), and building image and character episodes (BICE)—indicating that high variability seems to drive the way in which participants navigated the design processes. Such an analysis considered the number of episodes in each category and the time participants spent on it.

The revision of design diagrams showed that participants generated considerable variation in the number of diagrams they made across tasks, suggesting that architects use diagrams and sketches randomly to formulate design problems. However, the analysis also revealed that participants produced more sketches for the teahouse than for the events facility, and fewer sketches overall as the tasks progressed. Thus, the results of the analysis revealed that unknown design problems, represented by the teahouse task, required the

formulation of more diagrams and more DEs than familiar design problems, as we had anticipated for the unknown condition.

These observations are consistent with participant's opinion about the role that sketches play, as reasoning devices, in design formulation. Likewise, they are concordant with findings attained by design and cognitive science research, which indicates that diagrams and sketches, as external representations, are resources that designers use to formulate their designs. Consequently, our observations support our conjectures about how the participants were expected to produce sketches and with the notion of flexibility that sketches, as reasoning devices, support and allow. The analysis also showed that participants spent more time drawing floorplan representations than any other kind of diagrams and that they used floor plans differently from other kinds of diagrams, which was corroborated by testing correlations among the number of diagrams, drafting episodes, and the time spent on them.

Findings also revealed that architects used a small and discrete set of graphical elements to formulate their designs, regardless of the design brief, which consisted of straight and curved lines, arrows, squares and rectangles, circles, and labels. They used this set of graphical elements to represent design features and not as shapes.

In sum, the analysis of diagrams revealed considerable variation across participants and problems, as Table 10 shows, yet indicates the emergence of some patterns regarding the meaning they convey and the issues participants were dealing with. Thus, I notice that architects use the graphical elements that conform diagrams in a mechanical way, to address the subproblem in which they

were working. Further, from the analyses was plausible to infer that the role that diagrams play as cognitive artifacts that drive procedural strategies. We observed how architects began to draw even when they had no idea of where their design process was going. They used diagrams as mechanical procedures to address learned concerns.

### **7.3 Design issues**

The observation of participants using similar site and programmatic issues to explore design options suggested that they knew that among the issues they had to tackle were the room locations, the room connectivity, the entrance placement, or the site borders even before they knew the architectural program or the site. Thus, DIs emerged as key units of (declarative) knowledge that architects use to formulate their designs. Further observations revealed that DIs consist of two components; units of content and operations that are applied to such units of content. The observation of participants repeatedly using the same set of design issues to formulate their designs suggest they have internalized procedures for tackling such a common set of DIs. In other words, what they did was to settle on specific sub-problems for which they have developed procedures and tackled them regardless of the design task.

These outcomes can be summarized as two essential ideas: first, the idea that DIs are cognitive artifacts composed by semantic representations of architectural knowledge and operations linked to such representations; and second, the idea that architects draw from a discrete set of DIs to make the most of their design decisions. We suspect that such a common set of strategies is

nurtured during their training in architecture school and by acquiring such training, architects can bring to bear those strategies to approach unknown design problems. Further, we suspect that by using DIs, architects can translate design tasks given to them into something they could manipulate on paper.

#### **7.4 Variety and density of design issues predict design performance**

Outcomes of this study suggest that the likelihood of producing a novel design increases if the architect considers more DIs. The study revealed that quality performance in architectural formulation relates to the richness of design processes carried out by architects. Rich design processes are those in which architects tackle several DIs to make design decisions. Thus, variety and density of DIs emerge as a measure of richness for design processes. In this study, variety indicates different DIs and density the total number of DIs, which included repeated DIs. The results of the study also show that variety and density of DIs can be used as predictors of design performance. This dissertation tested both notions by studying associations between the scores assigned by the judges and the variety and density of DIs.

Design movements, or attentional shifts, were observed at various levels—within DEs and DIs—and as lateral and vertical movements. Another important observation that emerged from the analyses was that, along with an apparent lack of a pattern showing how participants made these design movements, the same units of declarative knowledge that participants considered while working out DIs might have played different roles since different operations were used on them. We also observed that design movements related to the substantial number of

design episodes in which participants adjusted, changed, and assigned values to design issues while drafting their diagrammatic representations.

### **7.5 On the research questions**

The dissertation introduced four research questions that guided the exploratory research and led to novel findings that contributed to our understanding of design processes and particularly of architectural formulation. The first question asked for how representations of architectural knowledge are organized and how they operated during the formulation stages. From the findings, we claim that representations of architectural knowledge are organized by units of content pertaining to the site, the architectural program, and the building character and image, and as a discrete set of operations that handle such units of content. In this dissertation, we observed that participants consistently recalled and used twelve units of content or architectural semantic representations and employed eight operations to make design decision with such units of content (Table 21).

The second question sought to identify the procedures that may come to play in transforming ill-defined design problems into defined ones. This research showed that determining which DIs serve as design constraints unfolds together with the construction of the design diagram, which consists of sketching arrangements of graphical elements (presented in Tables 16 and 17) bounded to (architectural) declarative knowledge.

The third research question explored the content of the reservoir that constitutes an architect's stock of knowledge. With regard to this question, we

identified a discrete set of DIs (Tables 20 and 21) that act as units of content and as operations in the framework of planning, which are implicated in monitoring and evaluating advancement in the solutions of design sub-problems.

Lastly, we sought to identify common cognitive strategies that architects use to define design problems. To that end, the study revealed that architects specifically break down a design problem into three categories of sub-problems with which they are more familiar. Such categories are related to the site, the program, and the building character and image. Whereas architects have a reservoir of procedures and techniques to tackle the first two approaches, they employ analogies and metaphors to face the third category. This dissertation called those sub-problems “design episodes.”

## **7.6 Contributions and future work**

The primary contribution of this study was to expand our understanding of architectural formulation. Such an expansion emerged from an in-depth revision of design episodes (DEs). The difference with the vast amount of studies that have based their analyses on DEs is that this research focuses on the myriad of things that take place inside episodes. Thus, the study, although bounded by its inherent limitations, showed three different layers in which the cognitive phenomena takes place for the case of architectural formulation. In the first layer, the research revealed that architects use a small set of declarative units of knowledge and operations to perform design explorations and to make design decisions. The research calls design issues the sets of pair conformed by units of knowledge and operations. In the second layer, the study noticed a connection

between design movements and rich design processes. Thus, design movements allow inferring both the variety and density of DIs, which are at the core of such enrichment and can be used as predictors of design performance. In the third layer of the cognitive phenomenon responsible for architectural formulation, this research revealed the way in which architects connect a small set of graphical elements to semantic representations of knowledge. Further, by dissecting such connections, the study demonstrated how architects assign semantic meaning to each graphical element until a graphical depiction of the DI under scrutiny emerges. Thus, as a consequence of the interplay of these three levels of cognitive processing taking place simultaneously, this dissertation postulates, the phenomenon of architectural formulation occurs.

The framework designed and used to perform this study is another contribution made by this dissertation. Such a framework permits the in-depth study of architectural design processes and could be used in other design domains as well. This assertion, however, raises a more general question: What do we have to gain from understanding the design process? The answer to this question is two-fold: First, for architectural practice, we know that the cost of design changes at the beginning of design processes is insignificant, yet the same changes in the construction phase have catastrophic consequences on schedule, budget, contracts, and even employment. Increasing our understanding of the way in which architectural formulation happens can contribute to increase design decision's certainty and to diminish the necessity for future changes. Second, for architectural education, the findings of this study may shed light on design studio practices, in which the relationship between the master and the apprentice



represents the dominant model of education. These findings can contribute by making explicit the nature of design episodes, the set of design issues, and the way in which architects link graphical elements and meaning to formulate DIs. Educators, on the other hand, might present cases, examples, and propose problems based on specific DEs or DIs so that students develop expertise in solving such sub-problems.

Further, the outcomes of this dissertation suggest several directions of research. Future work might address, among others, questions such as; given the results of this study and according to embodied cognition theories, what can be said about the role that categorization plays in architectural problem formulation? For instance, Lakoff and Johnson maintained that semantic representations of knowledge and spatial concepts such as those observed in this study are rooted in bodily states. Considering the results of this study, we could track spatial concepts (Table 22) to their embodied roots and further ask, how could such knowledge inform our understanding of architectural formulation? In the same vein, and revising the experimental set up used in the dissertation, is possible to ask how such a setup affected participants' performance? In addition, and regarding the specific role that the construction of diagrams plays for architectural formulation, future work could focus on better understanding the role that the topological relationships that emerge among graphical elements play in design decision making; then such topological relationships could be mapped to DIs. In the same vein, futures studies should explore that role that other aspects, not listed in the present research, play in the construction and appreciation of design diagrams. For instance, it is unknown how the appreciation of overall organization, neatness,

balance, movement, complexity, technical goodness, or even aesthetic appeal, affect decision making in architectural formulation. As can be seen, several paths open ahead of this research's findings.

## APPENDIX A: QUESTIONNAIRE

Volunteer Number:

1. Age:
2. Sex (circle one):

Male	Female
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3. Number of years studying/practicing design (architecture):
4. Do you use sketch as a design tool?

yes	no
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5. Do you use drawing board as a design tool?

yes	no
-----	----
6. Do you use computers as a design tool?

yes	no
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7. What role do ideas play on your design process?

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8. What role does sketching play in your design process?

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Thank you.

## **APPENDIX B: DESIGN TASKS**

### General Instructions

This part of the experiment asks you to solve four quick design tasks. In order to do this, you will be given two sites and two tasks. By solving task A in site A, task A in site B, task B in site A, and task B in site B, you will deliver four design proposals. Before starting, you will have 5 minutes to familiarize yourself with the tasks and the sites. After 5 minutes you will be asked to start. The researcher will keep track of time and will let you know one minute before time ends each time. You will have one minute to rest among tasks.

Before starting, you are provided with pencil and paper, a diagram representing the outline of the sites in which you will arrange your design proposals, a set of photographs of each site, and a handout containing the history and description of each task. A calculator is also provided if you want to calculate areas. You have seven minutes to propose each design using free hand sketches as the only medium of work. During this time you can write key words and/or sentences on your sketches to represent your design ideas.

### Design Task A

Design task A is to design a “space to perform the tea ceremony”.

The building must accommodate at least 30 persons and the basic requirements are:

An entrance space .....	200 Sq/ft
A ceremonial space .....	1000 Sq/ft
Two dress rooms with private bathroom (each).....	300 Sq/ft
Restrooms .....	150 Sq/ft
Storage .....	300 Sq/ft
Landscape / Green areas / Entrance pathway	
TOTAL .....	1650 Sq/ft

### Design Task B

Design task B is to design a "new facility to perform events and celebrate parties such as birthday parties or holiday parties". The building must accommodate at least 30 persons and the basic requirements are:

An entrance space .....	200 Sq/ft
A dining room space .....	1000 Sq/ft
Lounge .....	300 Sq/ft
Kitchen / Pantry .....	150 Sq/ft
Storage .....	300 Sq/ft
Cloakroom .....	100 Sq/ft
Restrooms .....	150 Sq/ft
Landscape / Green areas / Entrance pathway	
TOTAL .....	1650 Sq/ft

### About the Tea Ceremony



The Japanese tea ceremony, also called the Way of Tea, is a Japanese cultural activity involving the ceremonial preparation and presentation of Matcha, powdered green tea. In Japanese, it is called chanoyu (茶の湯) or chadō, (sadō, 茶道). The manner in which it is performed, or the art of its performance, is called otemae (お手前). The Japanese tea ceremony developed as a "transformative practice", and began to evolve its own aesthetic, in particular that of "wabi-sabi". "Wabi" represents the inner, or spiritual, experiences of human lives. Its original meaning indicated quiet or sober refinement, or subdued taste "characterized by humility, restraint, simplicity, naturalism, profundity, imperfection, and asymmetry" and "emphasizes simple, unadorned objects and architectural space, and celebrates the mellow beauty that time and care impart to materials." "Sabi," on the other hand, represents the outer, or material side of life. Originally, it meant "worn," "weathered," or "decayed." Particularly among the nobility, understanding emptiness was considered the most effective means to spiritual

awakening, while embracing imperfection was honored as a healthy reminder to cherish our unpolished selves, here and now, just as we are - the first step to "satori" or enlightenment.

### **Venues**

A purpose-built tatami-floored room is considered the ideal venue. A purpose-built room designed for the wabi style of tea is called a chashitsu, and is ideally 4.5 tatami in floor area. It has a low ceiling; a hearth built into the floor; shoji screens; an alcove for hanging scrolls and placing other decorative objects; and several entrances for host and guests. It also has an attached preparation area known as a mizuya. A 4.5 mat room is considered standard, but smaller and larger rooms are also used. Building materials and decorations are deliberately simple and rustic in wabi style tea rooms. Chashitsu can also refer to free-standing buildings for tea ceremony. Known in English as tea houses, such structures may contain several tea rooms of different sizes and styles, dressing and waiting rooms, and other amenities, and be surrounded by a tea garden called a roji.

### **Equipment**

Tea equipment is called chadōgu. A wide range of chadōgu is available and different styles and motifs are used for different events and in different seasons. All the tools for tea ceremony are handled with exquisite care. They are scrupulously cleaned before and after each use and before storing, and some are handled only with gloved hands.

The following are a few of the essential components:

- Chakin (茶巾). The "chakin" is a small rectangular white linen or hemp cloth mainly used to wipe the tea bowl.

- Tea bowl (茶碗 chawan). Tea bowls are available in a wide range of sizes and styles, and different styles are used for thick and thin tea.
- Tea caddy (棗 Natsume). The small lidded container in which the powdered tea is placed for use in the tea-making procedure.
- Tea scoop (茶杓 chashaku). Tea scoops generally are carved from a single piece of bamboo, although they may also be made of ivory or wood.
- Tea whisk (茶筴 chasen). This is the implement used to mix the powdered tea with the hot water. Tea whisks are carved from a single piece of bamboo.

### **Types of Temae**

Each action in sadō — how a kettle is used, how a teacup is examined, how tea is scooped into a cup — is performed in a very specific way, and may be thought of as a procedure or technique. The procedures performed in sadō are called, collectively, temae. The act of performing these procedures during a chaji is called "doing temae".

### **Tea ceremony and seiza**

Seiza (正座, literally "proper sitting") is the Japanese term for the traditional formal way of sitting in Japan. In that the Japanese tea ceremony is conventionally conducted sitting on tatami, seiza is integral to it. Unless it is the ryūrei style of tea ceremony, which employs chairs and tables, both the host and guests sit in seiza throughout. All the bows (there are three basic variations, differing mainly in depth of bow and position of the hands) performed during tea ceremony originate in the seiza position.



### **Tea ceremony and tatami**

Tatami are used in various ways in tea ceremony. Their placement, for example, determines how a person walks through the tea room, and the different seating positions.

The use of tatami flooring has influenced the development of tea ceremony. For instance, when walking on tatami it is customary to shuffle, to avoid causing disturbance. Shuffling forces one to slow down, to maintain erect posture, and to walk quietly, and helps one to maintain balance as the combination of tabi and tatami makes for a slippery surface; it is also a function of wearing kimono, which restricts stride length. One must avoid walking on the joins between mats, one practical reason being that that would tend to damage the tatami. The placement of tatami in tea rooms differs slightly from the normal placement in regular Japanese-style rooms, and may also vary by season (where it is possible to rearrange the mats). In a 4.5 mat room, the mats are placed in a circular pattern around a centre mat. Purpose-built tea rooms have a sunken hearth in the floor which is used in winter. A special tatami is used which has a cut-out section providing access to the hearth. In summer, the hearth is covered either with a small square of extra tatami, or, more commonly, the hearth tatami is replaced with a full mat, totally hiding the hearth.

It is customary to avoid stepping on this centre mat whenever possible, as well as to avoid placing the hands palm-down on it, as it functions as a kind of table: tea utensils are placed on it for viewing, and prepared bowls of tea are placed on it for serving to the guests. To avoid stepping on it people may walk around it on the other mats, or shuffle on the hands and knees. Except when

walking, when moving about on the tatami one places one's closed fists on the mats and uses them to pull oneself forward or push backwards while maintaining a seiza position.

There are dozens of real and imaginary lines that crisscross any tearoom. These are used to determine the exact placement of utensils and myriad other details; when performed by skilled practitioners, the placement of utensils will vary infinitesimally from ceremony to ceremony. The lines in tatami mats (畳目 tatami-me) are used as one guide for placement, and the joins serve as a demarcation indicating where people should sit. Tatami provide a more comfortable surface for sitting seiza-style. At certain times of year (primarily during the new year's festivities) the portions of the tatami where guests sit may be covered with a red felt cloth.

## APPENDIX C: JUDGES EVALUATION FORM

**Judge Number:**

**Volunteer Number:**

**Design Task Number:**

*Please fill the number of the design task that you are evaluating.*

1. Rate Creativity (Originality of idea). *The degree to which the design is creative and original, using your own subjective definition of creativity. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Creativity Comments. *Please add comments below:*

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2. Rate Novelty (Formal innovation). *The degree to which the design itself shows a novel idea. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Novelty Comments. *Please add comments below:*

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3. Rate Aesthetic Appeal. *In general, the degree to which the design seems aesthetically appealing to you. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Aesthetic appeal comments. *Please add comments below:*

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4. Rate Design Sophistication. *The level of sophistication of the design. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Design sophistication comments. *Please add comments below:*

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5. Rate Overall Organization. *The degree to which the design shows good functional organization. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Overall organization comments. *Please add comments below:*

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6. Rate Richness or Multi-valence. *Variety and number of issues considered in the design process: Site, program, materials, construction, use, visual qualities, style. Select a value from 1 (Very Poor) to 5 (Excellent).*

1      2      3      4      5

Richness Comments. *Please add comments below:*

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## APPENDIX D: CODING GUIDE

Design Episodes	A design episode is the time subjects spend facing one specific issue or feature within the overall design task. There are three main categories of design episodes: Design episodes related to the site, design episodes related to the program, and design episode related to design goal formulations.
Design Episode Site	<p>These episodes contain specific site issues being discussed by volunteers as constraints to their design formulation.</p> <p>Coding should be done considering start and end of the episode in which site issues are being discussed.</p> <p>Example:</p> <p><i>“Before I begin, I notice that this is a place I usually visit, almost daily, ahhh... it is also ahhh... circulation... place with a lot of pedestrian circulation... which I think is quite important to define design proposal...</i></p> <p><i>So according with this, according with the ahhh.. function of the building, that which is suppose that is a building at least for the entire Georgia Tech community, is not ahhh... for just one single academic unit, I think that the... the issue of the circulation can be used for defining a first proposal...</i></p>

	<p><i>So in that case... I think that my first diagram will consist on which I think are like the... main points and lines... that the circulation paths indicate in the... in the place... in the site... as well as... ahhh... some lines insinuated by pedestrian circulation... "</i></p>
Design Episode Program	<p>These episodes contain specific programmatic issues being discussed by volunteers as constraints to their design formulation.</p> <p>Coding should be done considering start and end of the episode in which site issues are being discussed.</p>
	<p>Example:</p> <p><i>"so for example rooms are bigger than the hall.. I'm not sure... maybe the hall is bigger, but the theater is bigger than the rooms... so, I want to work with those relationships..."</i></p>
Building Image and Character	<p>The main content of these episodes are specific design goals being discussed by volunteers as guide or constraints to their design formulation. On these episodes, volunteers talk about space, its quality, its properties, and the things they want to accomplish with their design. Also, the use of metaphors and analogies is frequent in these episodes.</p> <p>Coding should be done considering start and end of the episode in which site issues are being discussed.</p>

	<p>Example:</p> <p><i>“I wouldn't imagine this to be anything... bigger than one story, I would imagine it would be, uh... something that would span across the site. Something that would arc, in a sense, to take the... to take advantage of the view... And the light, since it's a ceremonial sacred space, you really... I feel like the water's calming, something that would...as opposed to a green area in the park...”</i></p>
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## APPENDIX E: INTER RATER RELIABILITY

<b>Design Episode</b>	<b>Source</b>	<b>Kappa</b>	<b>Agreement (%)</b>
<b>SE</b>	V05_1 Tea - Urban	0.34	79.64
<b>SE</b>	V05_2 Party - Lake	0.12	77.79
<b>SE</b>	V07_2 Tea - Urban	0.51	77.55
<b>SE</b>	V07_3 Tea - Lake	0.86	97.54
<b>PE</b>	V05_1 Tea - Urban	0.32	63.13
<b>PE</b>	V05_2 Party - Lake	0.11	46.55
<b>PE</b>	V07_2 Tea - Urban	0.17	84.48
<b>PE</b>	V07_3 Tea - Lake	0.49	84.32
<b>BICE</b>	V05_1 Tea - Urban	0.58	86.55
<b>BICE</b>	V05_2 Party - Lake	0.32	64.62
<b>BICE</b>	V07_2 Tea - Urban	0.21	60.87
<b>BICE</b>	V07_3 Tea - Lake	0.11	41.65
<b>Agreement</b>			72.06

## APPENDIX F: IRB APPROVAL

<b>Protocol H13035</b>	As Of: April 2, 2013 11:28 AM
<b>Title:</b> ON THE ROLE THAT PROCEDURAL AND SEMANTIC REPRESENTATIONS PLAY IN DEFINING EARLY ARCHITECTURAL DESIGN PROBLEMS	
<b>Principal Investigator:</b> <a href="#">Nancy J Nersessian</a>	<b>Current Status:</b> Approved
<b>Admin Assigned:</b> <a href="#">Melanie Clark</a>	<b>Last Activity:</b> 03/15/2013 - Approved Consent Forms Stamped
<b>Committee Assigned:</b> Central Institutional Review Board #1	<b>Original Approval Start:</b> 03/15/2013
<b>Review Type:</b> Expedited Review	<b>Current Approval Period:</b> 03/15/2013 - 03/14/2014

**Protocol Details** | [Related Submissions](#)

### Protocol Description:

The research has two different sessions. First, 25 architects will be asked to run two cognitive tests that measures IQ skills. Second, the volunteers will be asked to solve a design task. The architects will be allowed to use frehand sketches as the only medium of work to propose their designs. During the second session the participants will be video and audio recorded while solving the design problem.

### Department:

Arch

### Research Personnel:

Name	Role	Certification	Documents
<a href="#">Nancy J Nersessian</a>	PI	<ul style="list-style-type: none"> <li>Georgia Tech CITI Human Subjects Training Certification (Approved): December 8, 2000 - September 22, 2014</li> </ul>	
<a href="#">Paul Michel Bernard Verhaeghen</a>	CO-Principal Investigator	<ul style="list-style-type: none"> <li>Georgia Tech CITI Human Subjects Training Certification (Approved): May 8, 2012 - May 8, 2015</li> </ul>	
<a href="#">Sonit Bafna</a>	CO-Principal Investigator	<ul style="list-style-type: none"> <li>Georgia Tech CITI Human Subjects Training Certification (Approved): February 20, 2013 - February 20, 2016</li> </ul>	
<a href="#">Pedro Soza Ruiz</a>	Student	<ul style="list-style-type: none"> <li>Georgia Tech CITI Human Subjects Training Certification (Approved): February 2, 2011 - February 2, 2014 &gt;&gt; <b>! This certification may expire before the protocol !</b></li> </ul>	

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## **VITA**

### **PEDRO SOZA RUIZ**

Pedro Soza received a degree in architecture from the University of Chile in 1997. In 2001, he was invited to join the school of architecture at UNIACC university in Santiago, Chile. In 2003 he joined the faculty of Architecture at Andres Bello University and researched design processes and design computation. In 2004, Soza returned to the University of Chile and joined SIGraDi, the Ibero-American Society of Digital Graphics. In 2005, he was invited as a member of the jury for the International Biennale of Architecture at Miami Beach. In 2006 he was chair of the X international conference of SIGraDi, in Santiago, Chile. From 2007 to 2009, as president of SIGraDi, he was invited to be member of the international jury for FEIDAD, the Far Eastern International Design Award, in Taiwan. After presenting his work in design computation in Chile, Brasil, Mexico, Cuba and Peru, in 2008, Mr. Soza was granted a Fulbright Scholarship to pursue a doctoral degree in architecture in the United States. In December of 2013, he came back to Chile and became Director of the School of Architecture, Design and Geography of the University of Chile. In July 2017, Mr. Soza resigned to the chair position to pursue a research path. Currently, his work focuses on the study that procedural and declarative representations of knowledge plays in formulating early architectural problems.